Marine Safety and Environment
Ship Production
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          Inland Waterway Transportation
          2nd Conference Marine Safety and Environment, Ship Production
First Joint Conference on

Marine Safety and Environment
Ship Production

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S. Hengst
J. Klein Woud

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These proceedings cover shipping, harbours and shipbuilding activities, which in many ways are prime movers for the economy.

The sea, sometimes called the world's last economical resource, remains, because of the fast changing environmental conditions, unpredictable and sometimes dangerous. She is becoming more and more vulnerable to pollution, mainly from shore, but also from ships.

Safety and Environment require a continuing awareness of shipping, harbours and shipbuilders. This demands an integral approach to the entire system of this mode of transportation.

Shorter delivery times, methods for standardization and quality requirements are influencing the production cost and hence the price of the ships. Governments are planning to impose more stringent rules and regulations on shipowners and shipyards to improve the safety of ships.

Not all papers have been selected for inclusion. Some authors made a contribution with the help of slides only. These have not been included.

The proceedings contain the following main parts.

* Introduction
* A view of policy makers
* Ports, Moored Vessels and Transshipment
* Ship Operation, Simulation, Training and Automation
* Design of Ships and Machinery
* Construction and Materials, Full Scale Collision Tests
* Ship Production

We trust that the papers are of benefit to the readers and will induce all parties involved to improve performance and quality in shipping, shipbuilding and harbours.

The editors

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1 These proceedings are the first edition of a series on "Ship-Port-Offshore-Technology" and contain most of the papers presented at the "First Joint Conference on Marine Safety and Environment/Ship Production". The Department of Marine Technology is planning to continue this series. Other editions are planned on ship design, casualty analysis and inland waterway transportation.
Rotterdam Municipal Port Management

The field of operations of the Rotterdam Municipal Port Management is Rotterdam harbour. Together with the business world the Port Management is working to promote the interests of the world’s largest port. The Port Management’s main objective is to stimulate activity and attract operations which will provide added value and employment.

The organisation is therefore divided into three sectors:

1. The Port Management administers the port infrastructure and sees to it that there are sufficient sites, quays and harbour basins available, both now and in the future.

2. The Port Management pinpoints important developments as far as Rotterdam harbour is concerned. These are then translated into concrete plans for the future, in consultation with all parties involved.

3. The Port Management monitors the speedy and safe handling of shipping. Due regard for the environment is an important pre-condition in all of this work.
Opening of the Conference

J.R.H. Maij-Weggen, Minister of Transport and Public Works of the Netherlands

Delft University of Technology has been renowned in the field of applied sciences for a century and a half. In that time, it has witnessed many changes.

150 years ago, wind was still the main method of propulsion for ships. Mechanical propulsion only really came into its own in the second half of the nineteenth century. Meanwhile, early hydraulic engineers like the Froudes - father and son - in Britain, and Tydeman in the Netherlands were laying the scientific foundations of naval architecture.

Marine safety legislation, as we know it, dates only from the first half of this century. The first International Convention for the Protection of Human Life at Sea appeared in 1914. By 1930, the Freeboard Convention was setting minimum international standards for auxiliary motor capacity and watertight compartments.

Today, freighters are experimenting with carrying sail again, while large open top container ships have already found wind-assisted propulsion a resounding commercial success.

I notice that the brochure for this symposium carries a picture of a lightship. The faithful guardian of the shipping lanes makes an appropriate symbol for safety at sea. For the North Sea, though, lightships may soon be symbols and no more.

In a few years, the Netherlands will replace its last two lightships with more modern warning systems.

Which brings me to modern technological developments

The pace of technological change is hectic. The shipping industry - naturally conservative - can sometimes find it hard to keep up.

The master used to mix cargoes finds himself stowing containers instead. The navigator trained with a sextant has to learn satellite navigation. The radio operator brought up on Morse code finds he has a career in modern communications.

Change, of course, never stands still. Navigation charts will probably give way to electronic maps, linked to other navigation systems and updated automatically by a ship-to-shore data link. Vessel traffic services will improve, enhancing both safety and efficiency in port approaches.

Expectations are that it is going to be possible to pilot an increasing number of ships from the harbourmaster’s office.

The sophisticated technology behind all this - navigation and communication by satellite - is not just there for shipping. Air transport and road hauliers - "land-mobile users" in the jargon - have discovered its enormous potential as well.

But these are very expensive systems. Maritime users alone should not be asked to foot the bill for satellite navigation systems like the American GPS and the Russian GLONASS.

The Netherlands is therefore proposing that the International Maritime Organisation works jointly with the International Civil Aviation Organisation on setting up a navigation system for the 21st century. This would be a universal system to meet the needs of different user groups. It would aim for as broad a financing base as possible.

Technology is one aspect. We must also look at safety.

A great deal of effort has gone into technological developments in recent
years. Yet ships are crewed by people, not machines, and this is likely to be true for some time to come - computerisation or not.

Now, two features of shipping operations are significant here. One is the high intensity of contact between those on board and those manning shore facilities. The second is the fact that very few shipping accidents are due to technical failure alone.

Taken together, these phenomena explain the growing conviction that we should now be paying more attention to the relationship between people and technology, and to different forms of organisation in which people can work together - both aboard ship and ashore.

But what about safety at global level?

The setting up of the IMO as a permanent organisation in 1958 was a milestone in marine safety. The IMO has three main functions:
- to facilitate government-level collaboration on the technical aspects of shipping.
- formulating international policy on shipping safety
- preventing ships from polluting the sea.

Thanks to the combined efforts of virtually every seafaring nation, we now have a very high level of safety legislation. But despite this - as we all know - standards of safety are not as high as we would like.

Standards of marine safety vary widely from country to country. The Secretary General of the IMO said recently that the countries with the worst records were reporting 100 times more shipping accidents than those with the best. Of course, these are the extremes of a range: by far the majority of world shipping abides by the agreed safety standards.

But since the legislation is technically sound, the reasons for these global differences in safety standards must lie in different degrees of implementation and enforcement.

I would sum up the current position on safety worldwide as this:
- a small but unacceptable number of ships are unsafe (either because of poor maintenance or incompetent crewing)
- the existing system for detecting unsafe ships is not satisfactory.

Unless we can remedy this situation, different countries will move at different rates on safety, and the maritime world will end up with unilateral regulation and unfair competition.

The international conventions lay down that the registering state has primary responsibility for safety standards on ships flying its flag. Port states also have the right - and in my view the duty - to check that visiting ships meet the agreed safety standards.

The evidence from port state control is that some countries are not meeting their flag state obligations. The day of reckoning for them is not far off.

But to make our case watertight, we need more information about safety, costs and benefits.

Safety means eliminating hazards, and that costs money. Training people, building new ships to higher standards, modifying existing ships and their equipment, installing location finders, setting up vessel traffic services - these are all extremely expensive measures.

So safety measures need to be cost-effective - whoever is paying - government or industry. Safety at any price is a fine principle, but it needs to be set against the economic interests of the shipping industry and tight government budgets. There has to be some relationship between the cost and the effectiveness of safety measures. So we need information about the benefits of safety measures, which we can then weigh against their costs.
We also have to find some universally acceptable way of measuring different peoples’ perception of safety and danger. It should be possible to answer the question “How safe is safe?” using an agreed framework of parameters which define aspects of safety and within which practical safety issues can be addressed. This fundamental issue – relevant not only to the shipping industry – has numerous social, psychological, technical, and – of course – political aspects. It is currently the subject of a study on safety and water transport, to which this University is also contributing.

I should like now to say something about the other subject of this symposium, the environment.

The shipping industry is something of an environmental paradox. On one hand, the industry was one of the first to recognize the need for measures to protect the environment. On the other hand, merchant shipping is now widely blamed for damaging the environment.

There is no doubt that the MARPOL Convention led to a better organized and more environmentally responsible disposal of ships’ wastes. But that is no reason for either government of the shipping industry to be complacent.

The Netherlands government has just published the National Environmental Policy Plan for the Shipping Industry 1991-1994, designed to elaborate the objectives set out in the National Environmental Policy Plan.

Clean technologies can dramatically cut ships’ waste at source. Better working practices and operating procedures on board can also help. I am inviting the shipping industry to look closely at these aspects over the next few years. I hope that our new Environmental Prize for shipping will be an incentive. It shows, at any rate, how highly we regard the matter.

Much as I enjoy contemplating the future, I must not ignore the problems of the present.

Ships are still discharging oil illegally at sea. So we have announced a new package of measures in the Environmental Policy Plan for Shipping. Working in close collaboration with other North Sea states, we hope to put a stop to the practice by 2010.

The measures include a broad-based publicity campaign, better waste reception facilities in port – in terms of cost and quality of service – tighter aerial surveillance, more port inspections, and stiffer penalties for offenders.

Of course, these measures are not enough on their own. Government cannot solve the problem without a major effort from the shipping industry itself. It is not unreasonable to expect the shipping industry, with its long tradition of international cooperation, to exert pressure on rogue elements and stop these illegal discharges.

That the will for international cooperation exists was amply demonstrated at the March meeting of the IMO’s Marine Environment Protection Committee in London.

At that meeting, the countries present and the shipping industry itself agreed to far-reaching measures to reduce the environmental risks from oil tankers. The Dutch delegation pressed for – and got – a commitment to phase out the existing tanker fleet, as that becomes economically viable. The Netherlands provided much of the information before the committee, which also adopted new standards for double-skin hulls. This will considerably reduce the risk of serious oil pollution.

This historic meeting also saw agreement on tighter operational oil discharges allowed under MARPOL. The new standard will be that which now applies in especially vulnerable areas, those with “special area” status. As far as oil discharges go, all sea areas are now special areas – a policy that I have long advocated.
I find it immensely encouraging that governments and the shipping industry have been able to find consensus on such far-reaching measures. They call for a great effort on all sides, but our environment will be the richer for it.

Finally, let me say this

We face a challenge on the high seas. Scientists, shipping experts and politicians must now join forces to set our course towards a safe and sustainable shipping industry in the next century.
Welcome Address

P.A. Schenck, Rector of Delft University of Technology

There are many reasons to feel honored and pleased to welcome you here today at Delft University of Technology.

One reason is that in 1992 our University celebrates its 150th anniversary. On January 8th, 1842, King Willem II signed the official decree establishing an "Academy for the Training of Civil Engineers". From this Academy evolved the present Delft University of Technology when it got the right to award doctorates in 1905. This happened since that time about 2100 times; 84 honorary doctorates have been awarded.

The 150th anniversary was commemorated on January 22nd of this year in an official academic ceremony in the presence of Her Majesty the Queen.

A University is an educational and scientific institution. We therefore planned right from the beginning a series of scientific congresses covering as much as possible the fields in which our University plays an active role.

Many proposals have been put forward and a scientific selection committee ultimately accepted some thirty.

There are many reasons to pay attention to the maritime field. It was a deliberate choice in 1842 to have shipbuilding as one of the constituent disciplines of the Delft University of Technology.

Shipping, harbors and ships have been and still are, important for our economy.

Some figures may be an eye-opener for those who are not familiar with shipping, harbors and shipbuilding:

- Shipping takes care of more than 75% of the volume of the world trade,
- According to EC publications even more than 85% of the cross border trade within the EC is carried by ship, from this volume 60% is carried by inland waterway shipping.

The conclusion is obvious: without ships, shipping and harbors the economy of this world could never be where it is today.

There are other strategic and economical reasons which make the ship the perfect tool for the transport of cargo.

- The costs for transportation by ship are by far the lowest per ton-mile compared to other modes. The costs will of course depend on the size of the vessel, the economy of scale also applies to shipping. But the difference is huge.
- The capacity of the available infrastructure can be increased without any problem and is relatively cheap.
- The energy required per ton-mile is less than for any other mode of transportation, thus the transport is environment friendly and emissions are low.
- The mode of transportation is relatively safe. Incidental disasters, however, get publicity resulting in political attention.

The contribution of the maritime branches in the Netherlands is important. Approximately 25% of the Gross National Product of the Netherlands is generated by, or resulting from a direct relation to, maritime activities. The port of Rotterdam is the largest port of the world and the main-gate to Europe for cargo. Connections to the hinterland are for a great part canals and rivers and in inland waterway transportation the Netherlands holds nearly 60% of the European market.

Inland waterway shipping in Europe is based on one of the oldest European economical agreements: The charter of Mannheim dating from 1868.

Technology in ships and shipping appears to be longstanding:

- The changes from oar to sail and from sail to mechanical propulsion took nearly ten centuries, and still today we see that in sports the oar appears to be a good way to propel a boat.
The developments in construction materials, from reed to wood and from wood to steel, took even more time. The ship from reed is still existing. Wood is used as a basic construction material but is also used in advanced sandwich constructions. It took at least a century before steel was accepted as the most effective construction material for sea-going vessels.

On the other hand, the technological developments in offshore and shipbuilding are impressive. Examples are new designs, the advances in knowledge of ship construction and hydrodynamics, the increase in efficiency of propulsion over the last sixty years. The contribution of MARIN is worldwide acknowledged.

It fits into the tasks of the Technical Universities to educate people who are aware of their responsibilities and to carry out research which makes the development of environment-friendly ships, -shipping and -harbors possible.

The Delft University of Technology is aware of the importance of R&D for the maritime industry and wishes to play its role in the development of this international activity.

The department of Maritime Technology of the Delft University of Technology contributes to the research programmes with the laboratories of ship hydrodynamics and ship-construction. In cooperation with the shipyards in the Netherlands research in fast ship production is gradually being developed. R&D on harbour technology, transfer of cargo and inland waterway transportation is developed in close relationship with the industry.

The results of R&D are often not visible for the public, ships being at sea most of the time, far beyond the horizon.

This conference can contribute to a better understanding between the various disciplines involved in the maritime industries and the exploration of new areas for R&D.

The port of Rotterdam, as main-sponsor of the conference, and the industries which are participating in the exhibition, do recognize the relevance of safety and environment for the marine world and the significance of the role of the shipping and shipbuilding industry.

An historical exhibition gives an impression of ships and shipbuilding during the last 150 years.

I trust this will give you the right environment and spirit to make this conference a success.

This is the start of four days, concerning important subjects of discussion. I congratulate the organizing and scientific committees on their success in putting together an interesting programme, bringing to Delft international experts.

I do wish you inspiring days of lectures and discussions.

Delft University of Technology welcomes you on its premises and I wish you a good and fruitful stay at the University and a few nice days in this ancient town of Delft.
Summary and conclusions of the conference
S. Hengst, J. Klein Woud

The aim of the "First Joint Conference on Marine Safety and Environment/Ship Production" was:
• To bring together the parties involved in the maritime world and exchange thoughts about the safety of ships, and the environmental implications of ship operations.
• To establish areas for research, which are of common interest for the different parties involved to improve the safety of ships and reduce the pollution.

1. Policy

Apart from ship-owners and -operators, many parties such as shipbuilders, classification societies, insurers, seafarers, labor unions, researchers, educators, governments, port authorities and of course IMO are involved.

As has been stated by William A. O’Neil, the Secretary-General of IMO: "No Single Unit in the Safety chain can act alone but, instead, all must work in concert to achieve the common objective."

Particularly the safety of passenger vessels was addressed in this annual message for the World Maritime Day, but as Van Dorp [4.1.4] said, the words are applicable to all types of ships.

Also Rear Admiral Henn of the U.S.C.G. [1.6] is putting much emphasis on the promotion of mutual cooperation.

Many authors, amongst others Andersen, [1.4] are referring to the global competition in shipping and shipbuilding.

Shipping and shipbuilding are acting in global markets and all parties will have to realize that, in the long term, it will be impossible "to meet globalization by regionalization".

This means that the role that international organizations, such as IMO, will have to play, is becoming more and more important.

The international competition puts at the same time much emphasis on the economical aspects.

As stated by Busker [1.1] successful measures are possible, but "to every requirement a bill is attached and as obviously the parties interested in the maritime environment are not prepared to foot the bill by paying more for maritime transport, we see a continuous battle to cut costs."

Also Henn [1.6] underlines this: "The flag administration should help to ensure that the pursuit of international rules and standards do not create an unfair economic disadvantage for its shipping industry".

If the economics for first class quality ship-owners and -operators are not improved, will any attempt to develop a reliable planning for improved safety at sea and a better marine environment have a chance to succeed.

Rules, Regulations and Standards

The implementation of existing rules is not yet effective to avoid the operation of "substandard vessels". Ports should exchange and share information to reduce substandard performance. [Henn 1.6].

Several authors are suggesting the simplification of regulations. [Froese 3.1.2, Krappinger 4.1.1, Van Dorp 4.1.4 and Turner 3.2.1].

As a result of large (incidental) accidents the contrary is happening, according to Krappinger [4.1.1]. "Politicians start rushing for new,

1 Between brackets the number of the paper in the contents of the proceedings
additional regulations”. It may be even the case that due to political influences the IMO regulations are not always as good as they could have been.

Also Turner [3.2.1] states: “It is easy to compose extensive, bureaucratic systems which have no positive and practical significance”.

I.M.O. should have the courage to make a serious effort to review and simplify the regulations.

Some reasons have been given which support this view:
- The impossibility to fulfill technical requirements.
- The complexity, with the difficulty to control and implement.
- Rules are not always mathematically correct.
- The difficulty for the crew of ships to have the knowledge of a multitude of rules and instructions really available.
- Too much parties are involved, requiring sometimes contradictory regulations which cannot be met, because of local conditions in harbours (insufficient facilities or no facilities at all).

The deficiencies in the present systems should be corrected by having the different parties working together more effectively and more joint ventures should be fostered. [Henn 1.6].

An effort to review and simplify rules and regulations concerning marine safety and environment needs careful preparation. A thorough approach, supported by research programmes, is a key-element to develop sound regulations, which are to be based on a proper formulation of safety practice and ease of application.

Approaches as proposed by e.g. Froese [3.1.2] could be helpful to establish the area’s and levels where “disturbances” occur.

Such a programme should not only encompass aspects related to design, building and operation of ships but also aspects dealing with cargo handling during loading, transportation, unloading and storage.

Safety regulations of IMO for high speed craft need to and will be renewed. These regulations will emphasize the application of failure mode analysis and operational procedures, comparable to aircraft regulations.

From the variety of definitions being used by the authors, the need for a standard definition of safety becomes apparent.

It is clear that absolute safety cannot be obtained. The same can be said about the protection of the environment, 100 % clean ships are not possible.

The difficulty will be to establish, for the different phases of ship operations, an acceptable level of safety and level of pollution. In order to enable measurement of the results of efforts made by parties, there is need for quantification.

Reliability will increase due to improvements in design, manufacturing and feedback of operational experience. Regulations demanding reliability investigations are not yet existing but should seriously be considered by regulatory bodies.

An important conclusion made by Henn [1.6].

A concentrated effort must be made to improve sources and means of collecting casualty and performance data.

Using such performance data, a more scientific and rational based approach can be developed for improving marine safety. Particular emphasis should be given on the effect of human factors.

This will also lead to more technically sound regulations and help identify outmoded ones.

The use of statistical data should be stimulated and improved.

So far, much of the results of research is not being used because there
seems to be a discrepancy with the practical regulatory approach. The knowledge gained is being introduced in practice slowly, because of the lack of uniform application and implementation of the regulations. This does hamper the application of the feedback from accidents into practice. The introduction of new technologies makes some rules obsolete or not even applicable anymore to certain types of vessels. New technology can only exist if sufficient detail specifications are available.

Rules and standards should be "performance" orientated instead of providing detailed technical descriptions. There are many factors affecting safety, these depend on the operational phase or level and (port) conditions.

2. Ports, Moored Vessels and Transshipment

Ports play an important role in safety and environmental aspects of maritime transport. The papers of Hanekamp [2.1.1], Olson [2.1.3] and Baas [2.1.5] give numerical examples. Good pilotage, efficient Vessel Traffic Management Systems and Information Technology are of great importance when entering a harbour [Daniels 2.2.3], [Polderman 2.2.2]. Harbour reception installations for polluted ballast water, sludge etc. prevent pollution at sea [Velter, 2.1.2].

Port facilities should be a sensible balance between safety and environment and demands the subsequent costs. Increase of system cost cannot always be justified in view of decreasing damage and increased safety. Apparently the law of diminishing returns also applies to harbour systems [Deelen 2.1.4]. Not only harbour facilities are of importance but also the quality of the ships and crews entering ports [Mast 2.2.2].

Environmental aspects are related to ship operations in harbours and at sea. During operations vessels produce wastes, resulting from cargo (e.g. breathing of the cargo, CFK's from reefer vessels), engines (sludge, exhaust gasses) and coatings (metals from anti fouling) [Busker 1.1].

As explained by Krappinger [4.1.1] the interest for the maritime environment is growing due to incidental accidents.

Different figures are mentioned but still the major part of pollution of the sea is caused by pollution coming from shore. The estimates vary from 75 % - 100 % depending on the kind of waste.

The environment in harbours is primarily a matter of the port-side and the people living around harbours [Olson 2.1.3], however also here industrial waste from industry and shore installations play a major role. [Baas 2.1.5].

Major problems are:
- Hydro carbon emissions during loading/unloading.
- Exhaust gas emissions.
- Noise.
- Reception of wastes in ports.
- The lack of waste management and waste treatment systems.
- The pollution of soil, water and air by industry.

In general technical solutions are available but, at sea as well as on shore, economical and political considerations are the governing factors.

Technically it is possible to reduce the effects of pollution of ship operations, provided it is economically feasible. Still the effect on the overall pollution of the maritime environment is marginal since by far the largest danger for the maritime environment is coming from shore based activities.

Simulators will play an important role for the design of safe ports. This subject is further discussed in paragraph 3.

Ports do play a crucial role. Not only because of safety and environmental
aspects of ships in harbours, but also because of the quality of the ships and crews entering the harbours. [Hanekamp 2.1.1, Olsen 2.1.2, Baas 2.1.5, Mast 2.2.2].


Some of the major subjects presented in the papers were related to effects of sale and purchase of ships, involving the change of flag. Such a change of flag may for example be caused by different trading patterns of the ship or be a result of a different interpretation of the regulations. The role of governments is apparently increasing while at the same time the capability to handle and solve momentary problems seem to decrease, even when it concerns "united countries". [Henn 1.6].

Moreover the maritime world is facing a significant shortage of qualified and well experienced personnel. [Kelly 1.3]

The effect is a need for quality certification on a global scale, not only for the technical installations but also for ship operation and management. The role of the classification societies is mentioned in relation to the development of integrated quality assurance. [Smit 3.4.1, Mackenbach 3.4.2, Turner 3.2.1].

Integrated control and automation systems are capable to improve safety and improve the reliability of equipment to a certain extent. Technology, however, can only contribute to safety when at the same time additional education and training of seafarers and operators is provided for.

Many authors are mentioning human behaviour. The human factor remains a critical factor, even more when reduction in crew leads to the combination of different tasks of different levels for one man (supervising, decision-making, look-out, cargo-management and control).

Different causes for human failure are mentioned. The percentage accredited to human failure for the maritime operations do not differ much from aircraft operations [Smit 3.4.1]. Still the knowledge - through thorough analysis in which all parties are participating and contributing - should be improved.

Simulation, training and automation

In line with the developments in aircraft operations the use of simulators should be stimulated. As Damkjaer [3.1.1] states: "New training methods and means - of which simulation seems to be the most significant single one - are urging for implementation".

Various reasons are given for the use of simulators:

• The ability to assess the effect of automation on the crews' performance.
• Training and education have to be focussed on the fact that the seafarer is becoming more and more an expert operator.
• Casualties and accidents with ships can be analyzed and studied through simulation.
• Crews can be trained under different conditions and different types of ships on the same simulator.
• The safety of harbours and approaches can be evaluated.
• Particular environmental conditions for harbour approaches and entrances can be analyzed in order to develop safety criteria for vessels when they anticipate entering the harbour.
• Port developments can be analyzed for handling of ships under different conditions.

With respect to aspects of human behaviour the contribution of Froese [3.1.2] is of particular interest.

The role of information Technology is becoming apparent. [Hanekamp 2.1.1, Polderman 2.2.3, Al-Nakib: 3.3.3].

Information technology and Electronic Data Exchange (EDI) will become an important tool to improve on safety matters and environmental protection.
Information technology, improved communications, ship automation and voyage optimization make a voyage recorder, in combination with a transponder, a tool comparable to the "black box" for aircraft operations, able to analyze accidents and casualties, both at sea and in ports.

The contributions of authors on the subjects of "Voyage optimization" [Spaans, Andersen, Al-Nakib 3.3], "Ship Automation" [Keizer, Schuffel and Eijsink 3.5], Froese [3.1.2], Henn [1.6] and Smit [3.4.1], indicate that it is technically possible to obtain and record the required information.

The use of information technology will improve the capability to make an analysis of risks, dangers and harm to people, objects and environment in harbours and at sea.

Automation and expert systems as addressed in the papers of Keizer, Eijsink, Hobday and Klein Woud [3.5] indicate that human effectiveness may be improved and human failures prevented.

The question "how safe is safe enough" is not a matter of physical relationships or physical characteristics and the limits cannot be established by engineers.

A systematic approach as suggested by e.g. Stoop [4.1.5] and Krappinger [4.1.1] necessitates however the development of statistical design-methods applicable to ships, based on reliable information.

Again this is putting much emphasis on the position of the crew and on education and training of seafarers. Therefore the role of simulators will be to evaluate the effects of such things as:
- Crew reduction (behaviour).
- Multiple tasking [Schuffel 3.5.4, Damkjaer 3.1.1].
- The awareness of the crew.
- The increasing knowledge required for different operational and highly sophisticated systems.
- The combination of tasks and functions.
- The "tools" of navigation at open sea, in confined area's, approaches and harbours.
- Ship/shore support.

The use of simulators is therefore not only of importance for the behaviour and knowledge of the crew, it is also a tool which can support design of harbours, approaches to ports, as well as the design of the ship, e.g. with regard to aspects related to navigation and automation.

It is impossible for one party alone, e.g. the shipowner, to meet the conditions and overcome the limitations required to solve the problems. Recommendations are addressing all parties involved as can be seen from some suggestions:
- The responsibility for marine safety may be spread over several related parties in mutual cooperation.
- All ships should be subjected to common and equal regulations.
- More qualified seafarers, trained to higher standards of competence, quicker and more cost-effectively than provided by traditional methods. (Simulators).
- Certification in quality should become an international function as an international watchdog.

Suggestions for R&D are:
- More statistical and continuous research is needed for safety at sea, not only related to technical or environmental conditions but also to the human factor.
- Research to improve the human factor, especially in view of modern technology.
- Research to improve macro- and micro-navigation under all conditions.
- Research in automation and expert systems, which can improve human effectiveness.

The following conditions should be complied with:
International cooperation in achieving equal standards for equal competition.

Delegation of responsibility for marine safety over several parties means decrease of direct government control. Certification for ships by authorized institutes as proposed by Beukelman [4.2.1] and Froese [3.1.2] supports the same idea of spreading responsibility.

Government and IMO remain the main responsible bodies for marine safety, although delegation is required. The relations with other parties should be arranged and improved.

4. Design of ships and machinery

The usual approach of the designer is to develop his design in accordance with a given set of rules. The designer is not involved in the setting of the limits. He lives by the rules. This does not mean that the designer is not interested in safety or trying to improve safety.

The contributions from Huisman [4.1.3], Kasuaki Egi [4.1.2], Stoop [4.1.5], Beukelman [4.2.1] and Vossnack [4.2.3] indicate the continuous battle of designers to improve on safety of vessels. Different technical measures are proposed and introduced in ships which recently have been designed and built.

However, the problems of the designers with the existing rules are also apparent. Here also a clear call is made for review and simplification.

At the same time research is being done to develop tools to create a better understanding of the behaviour of vessels under different environmental conditions and of physical relationships between the different factors influencing the design.

The probabilistic approach mentioned by [e.g. Vermeer 4.2.2, Ferguson 5.2.1, Nibbering 5.2.3, Pegg 5.1.1, Kaminski 5.1.3 and Løseth 5.1.2] is gaining field and may be one of the tools to support decisions regarding the limits of "acceptable safety". One of the goals of the shipbuilders is to achieve low building costs, also in the design. Some shipowners have a more encompassing approach to safety and are more inclined to accept some cost increase for better safety [Huisman 4.1.3].

Feedback of operational experience is of utmost importance for safety. In this respect the shipowners design office is almost always in a better position than the yard design office.

An approach to integrate safety aspects into the design procedure is made by Stoop [4.1.5], who draws attention to the decrease of collisions between fishing vessels as a result of the introduction of the "Sea Days Directive" by the Dutch Government.

(The directive is intended to limit the number of days at sea, in order to reduce the catches).

The conclusion of Stoop is important.

"Although efforts on redesign may be promising, there is always a higher order in the system which is likely to influence safety levels far more drastically than any lower order".

This remark indicates the limits of the designer and underlines the importance of regulations and directives.

By going through the conference proceedings, the designer will find many areas which require consideration during ship design. They are related to behaviour of vessels [part 3.3] loading and unloading [e.g. Ferguson 5.2.1, Olson 2.1.3 and Baas 2.1.5] and operations [Busker 1.1], maintenance, reliability and safety [part 3.4] and automation [part 3.5], and the contributions contained in part 4.

Some conclusions are:

• Some regulations are hindering the designers to develop safer vessels. These regulations appear to be out-dated and flag states have problems in accepting new designs.

• Wherever possible regulations shall be performance orientated instead of descriptive.
R&D in design shall also be directed towards the development of tools capable to evaluate and support considerations on safety. Such tools shall include economical parameters to evaluate the effect of anticipated regulations on operational costs.

- Ships fulfill different functions and tasks. Conditions under which they operate may vary considerably. Therefore general standards and design procedures have a limited applicability. Standards should be set to different applications and environmental conditions.
- Aspects related to safety and environment shall form an integral part of the design procedure of ships and encompass all operational phases of the vessel.
- The use of simulators to improve the design of ships should be considered.
- Hydromechanic aspects of safety are in most cases defined for still water condition. The influence of dynamics (seaway, manoeuvring) is however important and shall be more incorporated in design methods and regulations.
- For environmental protection of tankers the double hull construction, trying to prevent breaking of cargo space, is not the only method to improve safety. Tank arrangements, which prevent outflow of cargo by means of hydrostatic balance can also be a sensible solution.
- As Ro-Ro-ships are, due to the low free board, prone to rapid capsizing, an improvement by means of addition of permanent buoyant material could be considered.
- Probabilistic methods may improve the assessment of environmental risks due to tanker damage and can give better judgment of alternative tank arrangements.
- Good manoeuvrability is an essential asset for safety of ships in confined areas. Dynamic simulation of ship and its machinery system can play an important role in the design stage to improve manoeuvrability.

Engine emissions

With regard to machinery emissions two solutions for improvement are possible.

The first is the "end of pipe solution", where the diesel engine process itself is not affected, but improvements are obtained through post combustion measures. A catalytic process which removes both soot and NOx has been described. Soot is removed by catalytic oxidation. NOx removal is obtained by means of a chemical reaction of the exhaust gasses with aqueous urea. [Hultermans 4.4.1].

The other approach is affecting the diesel engine process itself, of which two examples have been discussed:
- Combustion air conditioning, which attempts to reduce NOx formation by means of water injection in the combustion air before entering the combustion chamber. [Boot 4.4.3].
- Exhaust gas recirculation from the diesel exhaust into the intake side can considerably decrease NOx formation. [Hitziger 4.4.2].

Conclusions from these papers and the discussions are:
- Considering future requirements, engine modifications affecting combustion, may not give sufficient reduction of harmful emissions.
- Combustion air conditioning is a low cost, easy to be implemented method to reduce NOx formation. The reduction of NOx is however only 15-20 % in case no increase of fuel consumption is accepted and 35-50 % with some fuel penalty. This solution cannot meet future requirements either but could be adopted as an intermediate low cost solution with relatively good results.
- Exhaust gas circulation can give a considerable reduction in NOx formation, but tends to increase the formation of soot (particles) and incomplete combustion (increase of CO and HC).
- The catalytic oxidation of soot particles is restricted by high sulfur contents of fuel.
- Sulfur in the fuel leads to sulfuric acids, which can only be prevented by use of fuels without sulfur. It is therefore recommendable that regulations are going to specify that high sulfur fuels may not be used or even that fuel may not contain any sulfur. Fuel refinery techniques enable production of sulfur free fuel at the expense of some increase of fuel cost.
- NOx removal by means of reaction with urea is a very promising method,
which for the near future looks as the best method to considerably reduce NOx (90% reduction) as asked for by future requirements.

5. Construction and materials

The subject of ship structural design and engineering has been discussed from different points of view:
• The probabilistic approach.
• The detail design.
• Full-scale collision tests in combination with finite element calculations.

The contribution of Pegg [5.1.1] gives a review of the state of the art, and is interrelating these approaches.

Pegg concludes that:
"The difficulties associated with establishing uncertainties in the load, strength and limit state models are still considerable and it is difficult to imagine that a wholly reliability-based design code will be adopted for ship structures in the near future. Components may be incorporated into design practice ...." 

He indicates some areas for further research:
• The development of models for slamming, hydrodynamic pressure loads, see also Beukelman [4.2.1].
• The incorporation of human error into the safety assessment process (see also the contributions in parts 3.1 and 3.2).
• The development of improved methods for crack detection (e.g. Ferguson 5.2.1, Nibbering 5.2.2).
• The determination of target reliability values for design, maintenance and damage assessment.

An example of the combination of a probability calculation and costs is given by Kaminski [5.1.3] and the paper underlines the problems, indicated by Pegg.

Løseth [5.1.2] is stating that the analysis with help of probabilistic methods is useful for novel designs but are however expensive to make.

Examples of the complexity of the research required to support adequate reliability calculations are given in the contributions of Kmiecik [5.2.3] and Nibbering [5.2.2].

Both Ferguson [5.2.1] and Nibbering are making the connection to the practice of shipbuilding and the problems related to maintenance.

The contribution of Ferguson [5.2.1] is of particular interest, because links are made to ship-design, cargo handling, maintenance of ship, weather-routing and information for and training of the crew on board ships.

Although the contribution of Ferguson is dealing with bulk carriers some of his conclusions may be applicable for other types of vessels as well:
"The possible need to introduce a greater degree of structural reserve ....... thus making an allowance for a degree of human error."
"The need for awareness in the ship operating community with regard to damage to main frames caused by cracking, corrosion in the act of unloading ships."
"The need to prevent corrosion (in critical area's)."
"Experience gained with the use of higher tensile steels should be reflected in new designs."

Much of this is supported by Nibbering [5.2.2].

The attention for the detail in structural engineering, the proper execution of the details during construction and assembly, prevention of corrosion are of prime importance to reduce risks of cracking and failure.

The approach as presented by Andersen [1.4] confirms that some shipyards are working on these aspects of structural engineering.

The primary structural design of hulls seems to be satisfactory, provided,
as mentioned by Ferguson [5.2.1] that "the structure does not significantly
deteriorate locally to corrosion, physical damage on overloading."

A prime area for research is the engineering of structural details consider-
ing aspects on ease for production and maintenance (corrosion), fatigue and cracking as well on incidental damage (collisions, groundings).

Full scale collision tests

The aim of the research is to minimize spills of cargo.

A globally accepted safety level for all kinds of transport is desired as a base for the development of performance criteria by risk assessment. The designer then gets the necessary tools to comply with these performance criteria.

One of the tools is a numerical method to calculate structural behaviour of ships during collision. Tests results have justified the numerical method used for calculating ship collisions.

With regard to the numerical method further work on implementations of hydrodynamical aspects is needed. The numerical method is not yet checked for collision under small angles of incidence during which friction will play an important role. Further investigation is needed here.

In the numerical method the point of failure of fillet welds needs to be improved.

Calculation of the crush-worthiness is only one aspect. Further work is needed on:
- Establishment of accidents data base.
- Prediction of outflow behaviour.
- Structural deterioration.
- New structural design method.


A major item for R&D is the increase of productivity, through rationalization of shipyards, in order to remain competitive in the shipbuilding industry.

A comprehensive review of the developments and position of the European shipbuilding industry is given by Andersen [1.4], who argues that the Japanese shipbuilding industry is still considered by the Japanese government as being of prime importance for the economy. The theoretical basis for modern shipbuilding was developed in the Japanese shipyards through the introduction of planning and quality systems. Andersen mentions nine tools, available to maintain a competitive position, i.e. financial engineering, logistics, computer integrated manufacturing, innovative product design, precision engineering, production engineering, quality and safety, people and management combined with leadership.

The exchange rates are as important as the logistical chain, since 60% - 70% of the costs of a ship are materials which are to be purchased on a world-wide competitive basis. Trade restrictions of the E.C. are prohibitive for the competitive positions of both shipbuilders and supplying industry.

Distorting subsidies for the industry e.g. through the building of a "Fortress Europe" with trade distorting standards, should be avoided. The capabilities of naval architects, engineers and labour in Europe equal those in Japan. Well organized financial engineering and logistics contributes to the competitive position of the shipyards.

The developments in CIM are discussed by Van der Bles [6.3.1], Pieters [6.2.5] and Kennedy [6.2.6]. The importance of Computer Integrated Manufacturing (CIM) for the shipbuilding industry is growing.
The cost-effectiveness of CIM (relation price - performance) is not yet evident for all shipyards. This is also the case for technological developments for fabrication and application of precision engineering and QA/QC systems.

Large size shipyards have better opportunities to make these investments profitable than small and medium size shipyards. Suggested solutions are:
- Sharing the facilities [Hengst 6.2.3].
- Specialization and subcontracting.

The field of interactive computer supported production requires further research. The costs of hard- and software appears to be the controlling factor.

Precision- and production engineering (in some specific area's) are discussed by Mathu [6.3.2] and Fenn [6.3.3].

Both Mathu and Fenn indicate that the technology needs to be matured to make it applicable under the prevailing conditions during production.

Much more R&D will be required on the subjects of one sided submerged arc welding and the monitoring and control of automatic welding.

A successful example of precision engineering was presented by Andersen [1.4].

For small and medium size yards the possibilities of precision engineering in combination with CIM and automation/robotization need further investigation.

Aspects of QA/QC are covered in part 6.1. Quality assurance is closely related to management and organization. From the contributions it becomes apparent that, the costs related with the introduction of QA/QC (in accordance with the ISO 9000 series) may be prohibitive for smaller yards.

Fear for administrative overhead, paperwork with pertaining additional costs, is a drawback which is difficult to overcome.

Smaller size yards even may see a problem in the introduction of a system as presented by Golden [6.4], because the cost/benefit relation is not (yet) clear. The anticipated problem is the production of "documents for documents".

The introduction and use of QA-systems is depending on the support of the entire organization, from top-management to the workers on the shop-floor.

Part 6.2 (Shipyard performance) is dealing with people, management and leadership, as well as some aspects of logistics.

Well implemented QA/QC systems can considerably improve organization and reduce lead times in shipyards, but should be rather simple to administer, without additional efforts.

The contributions of Van Sliedrecht [6.2.1] and Kortenhorst [6.2.2] support this view.

Effects on costs, due to shorter lead times for production, resulting from further specialization in the production of e.g. subassemblies in combination with an increase in time, needed for engineering and production preparation (production engineering), demands further research to be able to evaluate and predict the overall effect on cost.

The human factor is a key-element to improve the overall productivity of shipyards [Van Sliedrecht 6.2.1].

The application of planning systems with "mile stones" in combination with more responsibility for quality and performance for the shop-floor are elements which are deserving attention.

The importance of the shipbuilding industry for the technical quality of ships is also mentioned by other authors [e.g. Van Dorp 4.1.4].

The role of the shipbuilding industry and the supplying industry is visible in various papers presented during this conference.

Quality has to become an integral part in the total production process of
design, engineering and manufacturing, to improve safety of ships and crews.

Concluding remarks

The contributions to this conference are providing the reader with a comprehensive review of the problems which the shipping and shipbuilding society is facing to ensure safe and environmental friendly transportation.

Two main conclusions are summarized:

• Shipping and shipbuilding act in global markets. A regional approach to problems whether related to subsidies, standards or regulations, will not provide any long term solution.
• Improving Marine Safety and Environment is to fail if the return on investment for first class shipowners in shipping will not increase.

Conclusions and recommendations

• A limited number of regulations, clear and precise, is needed.
• Only with the help of information technology, parties concerned can be timely furnished with the necessary data on regulations, dangerous goods, ship data etc.
• The same applies for the learning from earlier failures in a given system. Classification societies should play a role here.
• Cooperation at national and international governmental levels, Port State Authorities (PSA) and educational bodies is a must to guarantee fair competition, good crewing levels and the right human behaviour.
• The problem of necessary course duration must be dealt with a unified manner on international level for all educational bodies involved in the maritime education, naval architecture and marine technology.
• The use of simulators in the maritime world can greatly contribute to improved training and design of ports and ships.
• Many opportunities exist to improve competitiveness of the (European) shipbuilding industry. R&D on many aspects can be improved considerable.

Acknowledgements

For the success of the conference the contributions of the authors, session chairmen and participants to the discussions have been indispensable. This review with summary and conclusions is not only the result of a study of the papers presented during the conference but is also based on the contributions of participants to the discussions and the reports of the session reporters. The different views are reflected to the best of the knowledge of the authors. The authors wish to thank the session reporters for their valuable work: W. Beukelman, A.F.C. Carlebur, G.H. Doornink, J.L. van Herwerden, H.A. v.d. Hoeven, J.M.J. Journee, G. Koedijk, J.W. Koeman, F. Kok, F.V.A. Pangalila, J. Pinkster, K.J. Saurwalt, H.G. Scholte, W. Spuyman, J. Veitman and C.J. Verkley.
1. A view of policy makers
LR – the right choice

Lloyd’s Register has been the right choice for shipowners and builders since 1760.

LR is at the forefront of the industry, from the latest high-tech designs to investigations on existing ships.

And as the world’s premier classification society, we’ve made it our business to develop and maintain the highest standards in design and safety – enabling you to meet changing operational requirements and new legislation.
Shipowners view and responsibility
M.A. Busker

Close to 80% of everything the world population uses and consumes, is transported over sea. In weight a quantity of some 4 billion tons per annum.

To provide that transport facility some 70,000 ships above 300 GRT are in use.

All these vessels in their normal operation produce - cargo residues
- engine sludge
- exhaust gasses
- normal waste
- metals from anti-fouling paints.

Related to their specific transport functions:
- because of the breathing of the cargo, tankers release some 3000 tons of hydro carbons per annum to the atmosphere.
- fishing vessels produce fish waste estimated at 100 - 400 million tons p.a.
- reefer vessels release some 50 tons of CFK's per annum.

The repair, new construction and final scrapping of the vessels create an environmental problem of its own.
By nature of the diversification and geographi-
cal spread of these activities, with substantial variations in the development of the local regulatory machinery, it is not possible to quantify the effects on the environment on a global scale.

Please note we have excluded all vessels below 300 GRT and inland waterway, non sea going, vessels.

After this quantification, based on figures produced by some high profile internationally recognized institutes, it is time to ask ourselves: IS THERE A PROBLEM? The answer is: "Yes, but.."

The International Maritime Organization has created the machinery to tackle this problem with Marpol 73/78 and the annexes.

Substantial improvements have been made. From an environmental point of view it is significant that over the years the focus has shifted away from pollution by oil only.

There is a growing awareness of the effects of the environmental impact of pollutants we do not see, or are not perceived as a personal nuisance.

The interest for the conservation of the maritime environment is growing.
In The Netherlands "Green Peace" has 1 million paying members.
The public reaction following the Exxon Valdez accident has been a clear signal.

In general one can observe that in the industrialised world the efforts of IMO in the 60 and 70, leading to action by governments and industry, are now rapidly obtaining popular support and consequently a broader political base.

The negative effect of this awakening interest, is the inducement for politician to look for political i.e. short term solutions, rather than to follow the arduous path of international consultation and conventions, to arrive at long term solutions.

The major negative effect of this is a growing tendency to lay the burden of responsibility with the shipowner.

The pollution resulting from routine operations mentioned so far, cannot be prevented, only be influenced by the shipowner.

In order to do that successfully there will be required:
- a well maintained vessel
- the necessary technical provisions
- good operating procedures
- tight company discipline
- a competent crew.

All these things are well within the capabilities of the traditional shipping companies. Unfortunately to every requirement a bill is attached.

As obviously the parties interested in the maritime environment are not prepared to foot the bill by paying more for maritime transport, we see a continuous battle to cut costs.

The result of this being:
- an aging fleet as rates do not justify newbuilding
- very little R & D
- a constant streamlining of organizations
- a decline in discipline, due to new forms of labour agreement
- a different standard and level of competence of crews.

All developments not inducive to an atmosphere of greater care for the environment.

A different source of pollution is the accidental pollution. Here we see a strong focus on oil tankers. This for the simple reason that oil is highly visible and perceived as being
very bad because of, amongst others, the pollution of holiday beaches and seabirds dying.

Before passing judgement, things should be put in perspective.

Of the estimated 2 million tons of oil that flow into the sea every year, shipping is responsible for 24% or about 500,000 tons.

Of the total:
- 12% is caused by non tanker shipping
  - 7% is the result of tanker operations
  - 5% is the result of tanker accidents.

If we analyse the cause of the accidents, human failure is the principal cause. This either in the sense of an operational mistake, lack of maintenance or disregard of procedures.

How can we improve this situation?

The secretary general of IMO has expressed his concern and made a public statement, that shipowners were not capable to keep their own house in order.

In doing so a greater role for governments is implied. A recent example of government action is the USA Oil Pollution Act '90.

In an effort to protect the US tax payer against the effects of an oil pollution caused by a tanker accident, the very fundament of the
maritime insurance has been abandoned.

The Elizabethan Act of 1601 states:
"... that upon the loss or perishing of any ship there followeth not the undoing of any man, ...".

Under OPA 90 the principle of limitation of liability has been abandoned. The direct result of this being that well organized oil companies, with high standards of discipline, have abandoned their trade to the USA with their own ships. The same cargoes, with the same pollution potential, will now be carried in vessels of one ship companies. Because it is the shipowner that is held liable, instead of the cargo interests, this responsibility could easily be shifted.

In conclusion the OPA 90 can only be seen as a retrograde step in the battle against marine pollution.

On this side of the Atlantic, the EEC port state control agreement is a positive step ahead. However, do we control the right issues. In general a bad ship with a competent crew will seldom come to harm. The reverse of this situation is a formula for disaster. Still the quality and competence of a crew are virtually impossible to ascertain in a routine in-
Last but not least, the role of the salvor.

In 3 serious tanker accidents in 1991 some 100,000 tons of oil were lost into the sea. By extinguishing the fires, towing the distressed vessels to a less hazardous location and transferring the cargo, some 600,000 tons of oil were prevented to flow into the sea.

Please note all this took place in the open ocean, as in spite of all the talk about "safe havens" none such haven was made available!

The legislators have recognized the importance of the above and in the LOF '80, the standard salvage contract, a provision is made that even, if not successful, the salvor will be compensated for expenses made in efforts to avoid pollution.

In the new salvage convention '90, most likely a typing error has made the 1980 achievements null and void. That is called progress.

In summary:

- Holding the shipowner responsible does not solve the problem and is in fact counter-productive.

- The key element in both accidental and operational pollution is the competence of the crew and the level of discipline in the com-
- As long as society is not prepared to pay for the transportation of their goods, society is directly responsible for pollution caused by bad maintenance and lack of competent and disciplined crews.

- Internationally co-ordinated positive action will be the only means to control an international activity like shipping. Per definition it will take a long time before results are achieved and will be noticeable.

Conclusion:

As long as we are not prepared to ensure a reasonable level of earnings for the shipping companies, the pollution problems will increase and safety standards will decline, in spite of legislation.
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The principles of marine insurance
The view and role of Rotterdam Port Authority

P. Struijs

Port Plan 2010

One of the key functions of the Rotterdam Municipal Port Management consist of providing nautical services. The main objective is: supporting the economical process by realisation of an efficient navigation in the port, under the conditions of a sufficient safety level and limited environmental effects.

Safety is usually considered in terms of risk and thus as unsafety. Unsafty is counterproductive. Incidents result in obstructions in the logistic chain. From this follows that reducing unsafety prevents the loss of money due to damage or delay. Below a certain level of risk - in terms of probability of an accident - it is not useful to decrease this probability even further.

Safety inherent to the system result in an improvement of the system's efficiency. However, in everything the human factor is essential. That is why, the Rotterdam Port Management considers safety as a product: for safety is the result of people making an effort to handle things properly, showing a responsibility to prevent accidents and if accidents do occur having the knowledge, training and equipment to minimise the effects.

Following our main device it is clear that safety is no goal in itself but has to be evaluated together with other interests. This implies that a certain degree of risk has to be accepted. The key question is: which level of risk is acceptable. The appropriate framework for answering this question should be found in a safety policy.
Safety can be seen as divided into four aspects:

- Safety of the shipping traffic
- Safety in the transport of dangerous goods
- Safety of the (marine) environment
- Occupational safety.

In accordance with the overall objective of (promoting activity in the port and in the industry), two safety objectives are defined:

**Internal safety**
- To maintain a sufficient level of safety inside the port
This objective is aimed at the internal safety of the port and its industrial area. The intent of this objective is to ensure that all activities can take place unhindered by accidents, their effects or risks to public health;

**External safety**
- To maintain an acceptable level of risk to the public outside the port and industrial area
It is the responsibility of the authorities to protect the quality of life in the region from the hazards inherent to port activities. These activities must be conducted in such a way that all reasonable precautions are taken to protect the safety and health of the public as well as the quality of the environment outside the port;

Looking into more detail, the following objectives can be specified:
- prevention of accidents within the port
- limitation of the effects should accidents occur
A further categorization proves to be useful:
- 'daily' accidents, characterized by a high frequency and small effects
- large scale accidents, characterized by a low frequency and major effects
- catastrophies, characterized by a very low frequency and enormous effects

These accidents categories have their own prime instruments in the overall policy:
- For daily accidents physical planning in the main instrument. Prevention is rather difficult, so the effects can be limited by zoning as an instrument to separateport activities and urban areas
- Large scale accidents should be prevented as much as possible and the effects should be limited by scaling the incident fighting organisation and equipment to this type of accident
- Catastrophies should be prevented

The safety in shipping traffic can be seen as the internal safety of the system, the transport of dangerous goods is determining the external safety. Protection of the environment means safety for the system in the long-term.

The development are important as a base for planmakers decision.

- Developments in port infrastructure.
The newly developed harbour basins take into account the future trends in transport as part of the logistic chain. The existing nautical infrastructure, however, the fairways and basins, could not grow with the ships dimensions. So (nearly) every Port Authority has to receive those modern ships in basins, for which they were not designed. Adjustment of the infrastructure has been done as well, in a limited way, as this ultimate step is a very costly one.
- Development in human resources, the availability of skilled maritime operators.
Another development, that worries port authorities all over the world, is the future availability of pilots.

- Developments in tools.
Rotterdam is a safe and efficient port with low and stable accident rates. Monitoring the performances of all participants is of extreme importance to detect, in an early stage, deviations which might impair customers’ satisfaction or impair the safety records. Monitoring implies that tools must be available to process the monitoring feedback.

What is the answer of the Rotterdam port authority?
In order to satisfy the needs of the future port users with respect to efficiency and safety, looking at the aforementioned developments, the Rotterdam Port authority took the following initiatives.

- Improving the Vessel Traffic System. The VTS manages shipping, using all resources, such as the VTS itself, the harbour patrol services, pilot services, tugboat services. The Vessel Traffic System itself must enhance the quality of the port. Quality in safety and efficiency. The VTS is a decision-supporting system, enabling the traffic co-ordinator to decide and advise on movements of shipping. It has a vast information network, the Data Handling System. This is the administrative reflection of the actual performances in the port and can be seen as the real-time element of a Port Information and Management System (PIMS). A PIMS is the Port Authority’s managerial tool for making the right decision at the right time. To make past experiences readily accessible. To set strategic goals, as the past affects and limits potential alternative future scenarios.
Introducing the Waterdepth Management System. The Waterdepth Management System optimizes meteorological, current and water depth information as part of the date structure of the Vessel Traffic System. The objective is to provide the VTS operator with decisive information on hydro/meteo phenomena, its predictions and the influence on the keel clearance and/or tidal window of a defined vessel, en route to and alongside her berth. So the system provides information on whether a ship can, at a given time, with a defined draught (keel clearance) and a specific velocity, proceed safely from the entrance of the harbour to a berth and vice versa, and checks the draught alongside the berth during the first tidal cycle.

Introduction of the system will result in a more efficient operation and a reduction of ship delay times.

- Carrying out studies to define criteria to be applied in Nautical Quality Control within the port and, within the EEC funded Euret program, exploring the potential possibilities of a further introduction of shore-based pilotage.

- The last development to be dealt with here, refers to maritime simulation as important tool in harbour design, training, research and education. Manoeuvring simulators have got a wide range of applications during the last decades. They have proved their usefulness in the following areas:

  - engineering and port design evaluation;
  - training of ship’s officers and pilots;
  - port management support and trouble shooting.

At this very moment Rotterdam builds a Maritime Simulator Center, MarineSafety Rotterdam (MSR), compromising five manoeuvring simulators and a Vessel Traffic Simulator. The objective is to have in the Rotterdam area an assortment of skills and knowledge which in fact will be a Maritime Knowledge Center on port- and fairway design, its interrelated logistics; as well as on education and training.
The transport of dangerous goods:
Some figures:
- Seagoing:
  Approximately 45% of the total cargo in tonnes handled in the port of Rotterdam is classified as dangerous. 98% of this dangerous cargo consists of liquid bulk, of which crude oil is the main component.
  Around 51% of the number of ships entering the port carry dangerous goods.
  In 64% this implies the transport as packaged goods, like boxcontainers, tankcontainers, drum etc. Almost 95% of the notifications to the port authorities relates to this mode of transport.

- Inland barges:
  Per year approximately 23 million tonnes of dangerous goods are transported from Rotterdam by barge and around 7 million tonnes to Rotterdam. There are per year around 25,000 ship movements with dangerous goods to Rotterdam.

It will be obvious that the word "dangerous" only refers to situations where substances have escaped their containment. Thus, risk is related to accidents in which dangerous goods escape from their containment. Risk is considered as being a function of the effect of an accident and the probability of this accident to happen.

Especially the transport of dangerous goods forms a risk to the public outside the port area.

So the safety policy of the Port Authority must have the goal to minimise the probability of an accident and the effect of such an accident.
Looking at probability, a number of factors are of influence:
- type of packaging
- procedures
- actual method of handling.

A second factor is the effect of an accident. This effect may be influenced by a number of factors, such as:
- properties of the released substances
- the quantity released
- possibilities to reduce the effect
- planning.

One of the structural methods is the use of planning to separate activities with dangerous goods from residential areas.

The use of improper nomenclature is a well-known source of confusion when it comes to applying the proper rules or in case of incidents.

It was exactly this problem that made the R.P.M. decide to set up a database containing the necessary information: SISTER.

SISTER stands for Substances Information for Ship Transport and Emergency Response.

The system contains 4 functional modules:
- Substance Identification and Properties;
- Bulk Transport Legislation;
- IMDG-code Transport Legislation;
- Accident Information.

SISTER is not only designed for use during accidents. It is in the first place capable of providing ample information to the R.M.P.M.'s dangerous goods inspectors for their day-to-day job.
It is quite clear that a key-factor is the speed at which dangerous substances can be identified in case of accidents. A computer databank like SISTER is a powerful tool in making this data readily available.

As port authority we stimulate the use of SISTER in such a way that the receiver and sender of the Dangerous Goods Declaration could both use the same reference tables.

Possibilities for improvement are, besides the uses of telematics:

- uniformity in nomenclature;
- clear interpretation of legislation;
- no unnecessary delay in incident fighting.

Protection of the environment means safety for the system in the long-term. In the further development of mainport Rotterdam every attention will be invested in the environmental question in order to come to a harmonious cooperation between the port and its environment. Businessmen and businesses will not have to work and/or invest in a unsafe and polluted port over the longer term. Rotterdam supports the idea of a responsible development that will provide for the needs of the current generation without bringing into danger the possibility of satisfying their needs in the future. This does not mean that economic growth of the port must be restricted. Precisely as a result of the receipts from growth the investments for a healthy living and working environment can be financed.

Not only local industry and shipping cause hindrance and damage by pollution. In a port like Rotterdam, situated in the estuary of a major river system, polluted material from upstream industries, municipalities and shipping contributes to the total amount of waste material which may be found in the marine environment.
In the port we want such a water quality that the sludge can be dredged out of the harbour basins without any restrictions.

If the water in the port is polluted due to shipping or industrial activities extra (costly) precautions have to be taken in order to handle the dredged materials. Polluted water and/or sludge threaten the long term survival of the ports.

The Rotterdam Municipal Port Management has therefore developed a set of environmental programs.
- Prevention of the occurrence of waste materials or minimizing the quantities by improved unloading processes.
- To create ample facilities to dispose of waste materials that in spite of all measures do exist.
- Inspection that unloading procedures are followed and the facilities are actually used.
- An adequate administrative system to control the transport and disposal of waste material.
- Via the Rhine Research Project we are trying to make agreements with dischargers along the Rhine. The agreements are about reducing the discharge of polluted substances.
- Green Award. A vignette, which represents a certain score or percentage of a total rating, will give specified benefits to the owner and/or the operator of the ship when calling the port.
- Recently an information system on harmful substances has been developed in order to assist inspectors of different authorities with their task in port. The aim of the system is to assist the Department of Harmful and dangerous Substances of the Port Management by means of systemizing the information flow in order to enable the quick and efficient reaction on irregularities or potentially dangerous situations.
Ladies and gentlemen, as you see to be a port of the future you need quality, safety and a good, healthy environment, so to stimulate a better behaviour in the port, please pay attention to a project for the development of a quality-mark for seaships aimed at a better environment.

Thank you.
This is a very apt time to consider the way in which we train our seafarers today and to take stock of the various options which we must consider for the future.

For too long the joys of shipowning have been few and far between. Over the last decade and longer, forlorn shipowners could only wave their arms despairingly in the hope of rescue by the good ship "Profitability" - a hope which is not as yet generally fulfilled. This is the background against which many shipowners have had a "training holiday" - a plentiful supply of suitably trained seafarers was readily available world-wide, the responsibility for manning their ships was transferred by many owners to third parties, and the economic climate in the industry meant that setting aside funds for training for the future simply could not be justified.

The results of this are now becoming apparent. Most obviously we are facing a significant shortage of properly qualified and experienced seafarers. A report commissioned jointly by ISF and BIMCO in 1990 estimated that the current shortage of officers was approximately 10% of the total numbers required; moreover that this problem would become seriously acute over the next decade, for both officers and ratings, unless current recruitment and training levels were trebled.

But this shortage whilst the most visible result, is arguably not the most important. Many in the industry and outside would suggest that the major problem is the substantial decline in standards of professional competence over the past decade. They argue, with some justification, that, at least so far as Europe is concerned, one whole generation of highly trained seafarers has been lost as their jobs have disappeared and alternative employment found ashore. They also point out that those officers who remain are growing older and that the junior officers who are beginning to replace them (ratings too), now come predominantly from countries where education standards may sometimes be uncertain and training and certification standards less well regulated.

Whether or not these views of the decline in professional competence are an accurate reflection is debatable. But they are held by a significant number of owners and administrators in the industry, and increasingly by the public at large. We are already seeing the consequences - a growing trend to regulate how the industry operates, whether this be the Oil Pollution Act 1990 from the US Government or the introduction of mandatory safe management standards from the IMO. And if this were not indictment enough, you have the recent decision of those Administrations party to the Port State Control
Memorandum to the effect that not even a certificate of competence issued to an officer or rating by an Administration which has ratified the STCW Convention will be regarded as prima facie evidence that a ship is properly and competently manned.

But if the growing shortage of seafarers and concern about the standards to which they are trained are two particularly negative features there are also other factors which need to be taken into account when seeking a way forward. Two such factors:

Firstly, the type of work we need our seafarers to perform has changed and the numbers of seafarers on board has reduced. This must influence the type of person we recruit and the training we provide to them. Much of the manual labour, the routine maintenance work and many of the traditional maritime skills of officers and ratings have now disappeared, whether they work in the deck or engine departments. Even on relatively unsophisticated ships the seafarer is now expected to monitor information flows provided by technical equipment and to be far less of a hands-on operative. On the most technically advanced ships, a whole range of white collar skills are required to such an extent that the job is almost unrecognisable from that of even ten years ago. Whilst the ultra-low manning on these high-tech ships, with perhaps only six to eight seafarers on board, is unlikely to become the norm in the short term, I can see no reason to suggest that the long and consistent trend towards a general reduction in crew numbers will not continue.

So what do we need to do? Firstly we need radically to redefine the types of person we recruit not only in terms of their standards of intellect but also their mental aptitude for the demands of life at sea in a small community. Secondly and simultaneously we must review the training we provide to them against the work they will be expected to perform adding, where necessary, new skills and deleting those which are no longer relevant.

A further factor which we must recognise is that there are new methods and techniques available to us for the training process. Of these, simulators are perhaps the most powerful and obvious new training tool - new to merchant navy training, at least - and I have no doubt that my colleagues who addressed this issue yesterday will have described the many benefits to be derived from their use in training. They provide a real opportunity for seafarers at all levels to acquire skills rather than assuming that such skills will be accumulated during time spent at sea; they provide experience of how to cope with difficult or emergency situations which may be experienced rarely in real life; they can be an important means of demonstrating competence in particular techniques rather than relying on written or oral examinations which may reveal only a knowledge of the syllabus. Not surprisingly, the airline industry, from which we can learn a great deal, allocates some eighty per cent of pilot training...
to work involving simulators. But there are other techniques available to us, including computer-based learning processes allowing open or distance learning so that the trainees can attain professional competence in their own time and at their own pace. And with annual wastage rates of trainees and qualified seafarers often in double figures we could also learn another lesson from the airline industry and adopt a more efficient screening process for our trainees including, for example, the use of psychometric testing and profiling of ideal job holders.

Given the Industry’s objective of safe and profitable operations, the real significance of the techniques I have mentioned is threefold: they are capable of significantly improving the competence of our trainees, their use can enable this competence to be tested more effectively than traditional methods, and, by providing a more structured and concentrated form of training, we can reduce the periods of time currently required for training purposes.

In short we need more qualified seafarers, trained to higher standards of competence, more quickly and more cost-effectively than have been provided by traditional methods. Our future training strategy must take account of the reduction in the distinction between the work undertaken by officers and ratings, allow closer integration between traditional departmental boundaries and provide increased flexibility in terms of work and role for all seafarers.

ISF which represents over 50% of the world’s shipping has already embarked on a major initiative designed to help the industry to meet these objectives. We have started, appropriately, by concentrating on the principal international convention which regulates our training regime - the IMO Convention on Standards of Training, Certification and Watchkeeping. This Convention enshrines traditional work practices and departmental distinctions and is a real barrier to the introduction of more progressive and flexible patterns of work. But whilst it imposes a quite rigid, traditional approach to on board work organisation, and whilst the training regime and knowledge requirements which it sets for each officer and rating category reflect this, the Convention does not provide guidance as to the proper levels of competence which should be achieved in the various skills. The Convention thus allows individual Administrations the freedom to set their own standards, which in turn means that the gap between those Administrations maintaining the highest standards and those with the lowest is considerable. Owners therefore can have little confidence that any two seafarers holding the same STCW certificate issued by different Administrations will have received similar levels of training or be comparable as regards the skills they possess or their competence in these skills.

ISF submitted a paper to the IMO’s Standards of Training and Watchkeeping Sub-Committee last February urging a major review of the Convention taking due account of modern developments in the industry.
We believe that the Convention should be revised to provide a qualification system based on the separate functions which are required to be performed on board, such as navigation, stability, bridge and engine watchkeeping etc. This is in direct contrast to the present system which bases qualifications on the rank or position of an officer or rating in a traditional shipboard hierarchy, such as Chief Officer or Second Engineer. In our view, once the various functions which make up the total ship operation have been identified, competence can be defined as the standard of performance required to satisfactorily achieve the end result; and the actual degree of competence achieved can be determined by comparing evidence of performance, knowledge and understanding against a standard benchmark. Ideally such evidence would always include verifiable information that a candidate has satisfactorily performed a task or function on board. But it would be backed up as necessary by additional evidence obtained, for instance, from simulation and/or an examination as at present, to enable a judgement to be made regarding the candidate’s competence and capability to maintain consistent levels of performance (including in contingency and emergency situations). The advantages of this new approach are several:

- standards of competence will be enhanced, have universal application and interpretation and can be established without reference to scholastic achievement;
- shipping companies will be able to adopt the most effective manpower arrangements needed to meet the challenges of new ships and new systems of work, to cope with peak workloads and the avoidance of fatigue without increasing the crew size;
- all seafarers will be able to develop their careers as far as they are able and desire to, unhindered by artificial and out-dated barriers, leading to enhanced job satisfaction;
- the changes we propose would allow those Administrations and companies which wished to maintain the traditional approach to training and certification to continue as before, albeit with improvements in the competence of the seafarers to whom they issue certificates.

ISF believes that a revision of the Convention is a necessary prerequisite to other changes in the manpower and training field. The proposed change would ensure a greater degree of flexibility in the way in which seafarers achieve their competence, would encourage new approaches to education and training and would make it possible to measure ability against a recognised set of standards. It represents a major change in examination and training philosophy, though within the change there remains the flexibility to operate under current operational practices for so long as required.

The encouraging news is that ISF’s proposal for a major revision of the Convention has been accepted by the IMO, and
work will begin at the Sub-Committee’s next meeting, in March 93. So the debate on training for tomorrow has begun and you have just heard the ISF position. I do not pretend that it will receive unanimous support from all quarters or that the changes we need are simple or quick to implement. But few I believe would disagree with the basic premise that change is necessary if the industry is to operate safety and profitably as well as to recover public confidence. The safe and effective manning of ships world wide by dedicated well trained personnel is an integral part of this objective. I hope that you will share my conviction that the Industry is beginning to take the right steps in the right direction; though much has to be done and much of that, quickly.
Shipbuilding in Europe. Quality and Competitiveness. Globalization - Regionalization?
K. Andersen

ABSTRACT

In the past the European shipyards were second to none. However during the seventies and eighties they were overhauled by more productive yards in the Far East - and most of the European yards have not been able to compete since then.

In the discussion regarding the European reactions to this fact, parallels are drawn to the steel industry. It is argued that the past position can be regained if the Europeans would compete on price and quality instead of creating a "Fortress Europe" or trying to survive on subsidies. Put all effort and all resources into: financial engineering, logistics, computer integrated manufacturing, innovative product design, precision engineering, production engineering interaction, quality and safety, dealing with people, and management and leadership.

Europe's market share will be decided by her competitiveness on a global market with free world trade - hopefully.
"East is East, and West is West, and never the twain shall meet" (Kipling: The Ballad of East and West).

My first argument in this paper is rather simple: When demand exceeds supply, the producer can relax or even continue to sleep like the princess in The Sleeping Beauty. If on the other hand, supply exceeds demand the producer can wisely choose to meet the realities of the market and compete on price and quality - or he might choose to build a fence. Behind this fence he might try to sleep on, if the taxpayers are willing to contribute. The day they say no, there will be no doubt, the producer will be going to rack and ruin.

I dare not say that the young prince has come to Eastern Europe, but the Iron Curtain is for sure not a reality any more - Eastern Europe is facing the market mechanisms. The same situation occurred to the West European shipbuilding industry several years ago, when we met the Far East. But my question is: Did we react rationally, when Kipling's East and West met?

My answer is: no - for a long time economists in the West did not take notice of the rapid growth in the economy in Japan, South Korea, Taiwan, Hong Kong and Singapore. We overslept when the conditions for a global market became a reality - and I am tempted to say that we had too strong a respect for traditions so that what really happened was that the East "capitalised" on the Western technical innovations.

My second argument is: We cannot meet globalization with regionalization - only in the short term is it possible to survive on subsidies. The lessons from the steel industry and agriculture should be learned: trade flows are, by and large, dictated by economics rather than by government interference or unfair business practices.

The global market works - the challenge is to work with it rather than against it - this is what all involved in shipbuilding should realize, management, government and the EC-Commission.

If the European shipyards shall have a future, the tools are:

- Financial Engineering
- Logistics
- Computer Integrated Manufacturing
- Innovative Product Design
- Precision Engineering
- Production Engineering Interaction
- Quality and Safety
- Dealing with People
- Management and Leadership

West

The need for rebuilding the merchant marine was immense after the second World War. British and Norwegian shipping companies dominated the European scene, but in all countries with a maritime tradition the construction of ships was accelerated to the extend permitted by the economy.
The ships grew bigger and bigger, and the tankers made their entry in a larger scale. The technical standard was set by Shell, especially in cooperation with yards in Northern Europe. The Greek shipown-ers invested strongly, and with her 46,000 tdw. "Tina Omasis" changed our conception of how large ships could become. The expanding industry in Europe had immense needs for energy.

Not only oil was to be moved, soon transport of gas became a must. Also in this area Europe had the lead at first. Moss-Rosenberg, Technigaz, and other European firms created competing designs which to this very day dominate the market. But one thing is to design, another is to produce - to build.

In the first 20 years after World War II both economists and politicians had realised that expansion of Europe's economy to a large scale was dependent upon the shipyards - and for the managers of the shipyards this was not a secret and their influence on politics could certainly be seen. The shipyards had an important strategic role and they definitely contributed to full employment.

In the beginning of the seventies more than 400,000 persons were employed at the shipyards in Western Europe and, twice as many in the supply industry. This did not diminish the political impact.

**East**

Much was different in the Far East, still the similarities are obvious. Like Europe, Japan had to rebuild its fleet after the war and comparatively speaking this was much more important to Japan because the country was and is totally dependent on sufficient and competitive seaborne transport.

Japan "inherited" the technology developed especially by USA for mass production of the Liberty ships.

That Japan attached enormous importance to the industrialisation of shipbuilding can clearly be seen in the fact that they invited two Americans to play a leading role in development of this industry: the planning specialist Elmer Hann and the expert in efficiency and quality control Edwards Demming.

Dr. Hisashi Shinto became their "student", and he was the one who formulated the theoretical basis for modern shipbuilding in Japan - and elsewhere. He applied Boeing's design technology to shipbuilding and began with quality circles already in the fifties.

In 1964 the Japanese share of the market surpassed 40% - and Japan built more than the nearest five countries combined.

The oddity is, that no economist had foreseen this success - and when it was a reality it took us all very long time to realize the fact.

**The European reaction to "The Ballad of East and West"**

In the fifties USA had the leading role in international shipbuilding - but the trend was obvious - and can be seen in Kaisers goodbye.
It took Europe many years to realise that Japanese shipbuilding had been industrialised - and thereby was competitive. This might be due to some international incidents, incidents that prevented us from seeing through the smokescreen.

The Suez crisis in 1956 meant that the demand for oil transport exploded. The existing yards could not comply with the demands. For this reason a lot of money was invested in new yards in the sixties.

The shock came with the oil crisis from 1973 to 75: There were too many tankers on the market. Much less had to be transported, the growth in economy and in consumption of energy diminished rapidly - and Japan was still ahead. This was finally realised in Europe. How did we react to this situation? - well, we can all remember: it was un-European to drive in a car from Japan. If you did, you could risk bumps and scratches when the car was parked.

Many shipyards declared themselves bankrupt - and it took only a few years before almost every big yard in Europe was State-owned. Competition was not in focus, no, attention was given to employment.

In Sweden - which in many ways was number one among the European shipbuilding nations - all the yards were closed, the working force could be used elsewhere. Norway and Holland too experienced the consequences from the crisis - and several new yards in France, Spain and Portugal had no orders.

On top of this South Korea became active in the market. They had constructed the biggest yard seen so far - and this was the beginning of an enervating price war between Japan and South Korea.

Every shipyard lost money, but Europe suffered most strongly from the crises - Europe's share of the market was halved.

Not only had the European yards new owners - the State - but on top of this new managers - often politicians. The acquaintance with the market was decreased, and totally unrealistic decisions could be experienced, dispositions that often contrasted to the rationalizations the Japanese undertook.

To this must be added that Europe was paralyzed by the events in 1968. Profit was a word with very strong negative connotations - and there was a tendency to replace industrial politics by social politics.

The European answer to the rationalization in the Far East was to cry: "unfair competition" - and the medicine for Europe was "subsidies".

The situation today

The market price has gone up - and money can be made on shipbuilding, but the real money is made in the Far East. Several of the European yards are still suffering losses. The subsidy policy is threatening the progress.
The differences between the shipbuilding industry in the Far East and in Europe have certainly not been diminished since the crisis began - the only thing constant is our refusal to face the realities in a constructive way.

When we compare productivity in Eastern and Western Europe there is no doubt, we are far ahead in the West. But somehow we are reluctant to acknowledge that the gap between Western Europe and the Far East is of the same dimension when shipbuilding is concerned.

Still, the differences are obvious at all levels:

The welding machinery in Japan is much better, the steel to be welded is of much higher quality and much more welding is produced. But that is only one example. The leaders are more experienced and much more and much better trained. At the top they are few, they can cooperate and most of them are highly experienced shipbuilders.

In Europe most welding in shipyards is still based on hand carried, covered electrodes. In Europe we have problems with the steel, it has to be preheated, when high quality weldings must be achieved.

The management structure at the European yards is generally such that the need for overhead is much bigger than in Japan. Often the goal is to provide employment for more and more people - without regard to efficiency. This ultimately requires increased subsidies.

If you visit some of the European yards you will see 20 years of negligence in investment and maintenance. Many yards are cramped and the main impression is often that of disorder and mess. Their contribution to an improvement of the image of the industry is rather small. Quite the opposite, the combination of decay and a grandiose and excessive administration creates a bad image.

Furthermore, I believe that the industry does not manage to respond with concerted and constructive proposals, when the EC advertises for initiatives. Instead of concentrating effort and money in development of productivity the demand is for further subsidies.

A few percent of the amounts spent on direct production subsidies would make a dramatic impact if it was used for Research and Development.

The future

It is normally difficult to predict the future but that is not the case for European shipbuilding if we continue our policy: The European shipyards will survive as long the governments (read: taxpayers) are willing to pay the bill, which by the way is getting bigger every day.

On the other hand, the cure is very simple: Put an end to the subsidizing policy. This will lead to a purge similar to the one mentioned in the ancient mythology where king Augias' stable was full of dung from 3,000 oxen. Heracles mucked out the stable by leading the water from two rivers through.

We are at the crossroads. We can continue along the road paved with subsidies, we can remain in "Fortress Europe" - or we can confront ourselves with the realities of globalization. Two
rivers are not needed – only financial engineering, logistics, computer integrated manufacturing, innovative product design, precision engineering, production engineering interaction, quality and safety, dealing with people, management and leadership.

If Europe leads the way I am convinced that Japan and Korea can also be persuaded to refrain from unfair trading.

**Financial Engineering**

Shipping is almost by definition international, and currency fluctuations are therefore of immense importance. USD and YEN are dominating and their exchange rates often vary substantially.

No yard can expect to stay in business unless these problems are dealt with, and included in the proposal to the shipowner with equal care as traditional engineering is included.

The development in the exchange rates for some of the important currencies is shown in fig. 1:

![Graph showing exchange rate development](image)

**Figure 1: DEVELOPMENT IN IMPORTANT CURRENCIES**

1st Aug. 89 to 1st Mar. 92

For a shipbuilding contract which normally runs for a long period, the forward rates are highly important. In fig. 2 the development in forward rates is shown under the condition that the exchange rates on the spot market are constant. A fluctuation of more than 5% of the contract price for a vessel can be realized in six months, even with constant spot rates.

The development in VLCC prices since 1975 is shown in fig. 3, 4 and 5.
An owner will today expect that the shipyard presents proper financial solutions tailored to fulfill his needs. Financial engineering is a discipline with steeply growing importance.

Figure 2: 2 YEARS FORWARD RATES ON USD
Fixed USD/DKK base at 6.50

Figure 3: DEVELOPMENT IN VLCC PRICES IN VARIOUS CURRENCIES
250,000 dwt
Figure 4: DEVELOPMENT IN VLCC and VW GOLF CURRENT PRICES IN DEM
basic VW model and a 250,000 dwt VLCC

Figure 5: DEVELOPMENT IN VLCC CURRENT PRICES IN USD, DEM AND YEN
250,000 dwt
Clearly the rate of exchange for YEN and USD against DEM is extremely important for the European Shipbuilding Industries. Shipbuilding has no market where the DEM is of real importance.

The unnatural high rate of interest for DEM, which is the result of the German unification, has reduced the value of USD and YEN dramatically and thereby affected the competitiveness of the European shipyards similarly.

At the same time the German Government infused 3.6 billion DEM of taxpayers' money into the German shipyards over and above the limit set by the EC-Commission.

The action of the German Government will create new shipbuilding capacity which is certainly not needed and for which there is no market. The result being that world market prices for newbuildings will be further reduced.

The European Shipbuilding Industries will suffer greatly. While the German yards on average are generously compensated by the taxpayers for the adverse exchange rate situation.

**Logistics**

Costs are influenced heavily by logistics as some 60 - 65% of the cost price of a ship are material. How they are specified, where they are bought, how they are transported, sorted, inspected and made ready for installation should be organized in a logistics function.

Computer systems and advanced means of communications can solve most of the traditional tedious problems, but it is still up to responsible people to ensure that material shortage is fully eliminated. It can be done, and prosperous yards of the future will be masters in this discipline.

The average material purchases 1988 - 1992 for a competitive shipyard in Europe is shown in fig. 6.

![AVERAGE MATERIAL PURCHASES 1988 - 1992](image)

It is obvious that a requirement that European yards should buy all their equipment in Europe will lead to a disastrous loss of competitiveness.
40 percent of all equipment is bought outside the EC. However, the competitive European suppliers are selling even more to the shipyards in the Far East. So they would also suffer from trade restrictions. It is in the interest of European shipbuilders and their supply industry to resist all "Fortress Europe" proposals.

**Computer Integrated Manufacturing (CIM)**

With all due respect to the importance of any other discipline, CIM is definitely the most significant difference between "the good old days" and modern shipbuilding. So much has been gained by computers already and even more can be seen as potential. Only our capacity for imagination puts up a limit.

The positive CIM effect correlated to time is shown in fig. 7.

A full 3 dimensional topological model of the ship and all its outfitting has opened a whole new era for modern shipbuilding influencing virtually everything from the preparation of the first schedules through computation of fluid dynamics, structure definition, strength and noise calculations, cost estimates, work content calculations, bills of materials, simulation of fabrication, generation of drawings and NC data for cutting, welding, painting, and transportation automation to production of quality documentation and user manuals.

Japanese shipyards and some in Europe have worked intensively to develop and implement relevant CIM-systems for 8 to 10 years. Results are now clearly appearing and widening the gap between inefficient and efficient yards.

Developments within other industries and related technologies will facilitate increasingly profitable utilization of CIM. Super computing, ultra high speed data communication, new mathematics, sensors, neural networks, artificial intelligence are all contributing very efficiently and opening new possibilities for improving the competitiveness of the advanced shipyards.

![POSITIVE CIM EFFECT](image-url)
Innovative Product Design

The time it takes to generate a new design is certainly critical for any industry but because of the size and the price of ships it is even more important for shipbuilding. At the same time a modern ship is the most complex unit anyone can dream of. It contains all the functions and facilities of modern civilization, and on top of that it has the ability to operate under each and every condition imaginable on our planet. And it works 24 hours a day and more than 360 days a year - usually for 15 - 20 years so no wonder that life cycle considerations have a very special meaning to shipbuilding.

Given these facts, innovation in product design becomes essential. It has to take into account the possibilities in virtually all new technological development, and relate these to the needs of the customer and the specific needs of the yard’s production facilities - and time is still critical. Optimization requires skills, tools, experience, and creativity. We find here the challenge which has got to be considered as the very core of the company culture. Facilitating team spirit and joining all forces is the name of the game.

The following simple index summarizes innovative product design:

Design index= \[
\frac{\text{Value of product for the owner}}{\text{Total cost for the yard to produce}}\]

Precision Engineering

Carefully detailed design and optimized tolerances are the most important measures to achieve efficient production utilizing a high degree of automation leading to a highly reliable final product in which fatigue problems have been minimized.
The ship should be designed and constructed on a "Precision Engineering" basis: it should be designed to accepted tolerances, without regard to potential variations in materials, and built to meet those tolerances.

To demonstrate the idea an example has been given in fig. 9:

The size of a ship is not that easy to measure simply because of the dimensions. There is no fancy weight available - ships are the biggest things man can move.

Still the individual components have to be fitted together with an accuracy allowing the newest and most sophisticated welding methods to be used, and although the propeller diameter might be close to 10 m the shaft and bearing have still to be measured in 1/100 of a millimetre.
Application of NC equipment for cutting, marking, positioning and welding has opened for a new higher level of accuracy and this again is allowing new assembly methods to be applied. This means dramatic cost reductions but it means also a better structure with much less built-in tension and much better strength and fatigue abilities. Application of lasers will further expedite this development.

This will lead to competitive advantages in several important areas: Costs, vibrations, strength, maintenance.

Production Engineering Interaction

Very often the term "Production Friendly Design" is used to describe a potential which should be so obvious that it is self-evident: Decisions made at the design stage is a determining factor, also for production. The tool to achieve this is interaction between Design and Production handled by the Production Engineering Function. This will determine how much can be automated, whether access is easy or complicated, whether there is room for supplies or space is too narrow to allow efficient operation. The process requires skills at the highest level and very good tools, but most of all: The right attitude by people involved.

I am sure that the attempt to develop a design common for several yards in Europe having individually very different production facilities, is doomed to be a failure although politically it seems to be preferred. A common design will result in compromises, which will subsequently create awkward problems in the production for most yards. One single unfortunate design feature can increase the consumption of man hours with 15 - 20% for a given yard.

Quality and Safety

Much has happened in the QA field over the last years - even in our part of the world. It is probably the area where there is broadest acceptance of the Japanese achievements. Quality can never be inspected into a product, and quality control departments have definitely done a lot of harm in this respect. There is one way only, and that is to make one and all understand his specific responsibility. Through such understanding very valuable improvements are gained and gradually the close relations between quality and safety become the driving mechanism in mobilizing the organization such as: Zero defects and Zero accidents are no longer an unrealistic dream.

In Japan and in some places in Europe "green materials" for blocks to be erected in the dock or on the slipway is unknown today. The precise fitting together is a matter of course.

Dealing with People

In an organization no resource is so important and vital as the human resource. A shipyard is certainly not different, but once again we have extreme possibilities of either being the very best or the worst.

To build ships can be dirty, hard work, even dangerous, if proper concern is forgotten, but it can also be the opposite and we have an advantage as only few industries: The final product.
It should be obvious, that our people deserves neat and clean conditions and the best equipment. Likewise, we have to give them training, not only to improve their skills, but to motivate them. We have to make sure that a bonus is always the response to a well done job and the incentive to further productivity increases.

The organization must have entrepreneurs and teamworkers, and "dead wood" as a result of social politics should be totally avoided.

Management and Leadership

There is a very big difference between a manager and a leader.

A shipyard can be operated by managers, no doubt, but if improvements are asked for, leaders must be an integrated part of the organization. Balancing team workers and entrepreneurs is critical. It is the most difficult of all disciplines. Top management will be judged by their ability in this fine art - the shipyards' vitality or even survival will depend on it.

The Past, the Present and the Future - once more

The above described tools are certainly necessary in our fight for survival - but every improvement can be destroyed by a misleading industrial policy. Let me illustrate this by "the welding window".

The welding window is a picture used to summarize the demands of all welding parameters if a welding shall be of the right quality. In fig. 10 a drawing has been made to illustrate the welding window's relative area in Japan and in Europe.

Why is the European window that much smaller? Primarily, because it is much more difficult to weld the European steel. At times the European window is even negative - in that case it is necessary to preheat the steel to 80 - 120°C to achieve a satisfactory welding. Or expressed in a different way: the productivity in Europe is smaller, and the demands for qualifications of the welder are much higher.

When welding in European steel, many more faults are likely to appear and the final quality might be substandard if severe quality control is not enforced. It may unfortunately turn out to be very difficult to utilize laser welding in European steel qualities whereas it is quite feasible in steel of Japanese standard quality.

To this must be added that the Japanese yards are paying the same price for the better steel that we are for the lesser quality.

The result is that the man hour consumption for welding may well be 10 percent higher in Europe only due to differences in steel quality.

Why are we in such a situation? Because the steel industry in Europe "succeeded" in convincing the politicians that the industry
could only survive if it was protected and supported by subsidies and import restrictions - and behind the erected walls there was no need, and no incentive to develop a quality product.

CONCLUSION

It is my sincere hope that the European Shipbuilding Industry will regain its past position as world leaders in competitiveness, quality and product innovation.

This position may be achieved if we act as I have argued in this article. We have to realize that the Japanese yards do not owe their present position as leaders to unfair trading practices. They are efficient and competitive. That is our starting point.

It is a must for real European progress and the free world trade that all distorting subsidies be ended. Such subsidies include the following:

- Subsidies based on aid to developing countries for ships for use in international trade.
- Subsidies based on phony currencies to fool the OECD rule for rate of interest subsidies.
- Unrealistic investment subsidies to former East German yards owned and integrated economically with Western yards.
- Huge subsidies to re-open yards which were subsidized by EC to be closed a short time ago.

Important persons have said that Europe has the right to a certain part of the world market for shipbuilding, and if this market share cannot be achieved on commercial terms it must be provided by political means.
I totally disagree.

The market share Europe deserves and should have must be decided by her competitiveness and nothing else.

The EC-Commission has recently proposed to assist the European Maritime Industries by establishing European Maritime Forum in which shipowners and the supply industry will also be represented.

The proposal has been welcomed by a majority of shipbuilders in Europe. A minority, to which I belong, warns:

If the intentions are to build a "Fortress Europe" with trade distorting standards, European built ships for European owners, European equipment for European shipyards, to support the inefficient yards at the cost of the efficient ones etc. etc., it is believed that the forum will be another nail to the coffin for the dream of a COMPETITIVE European Shipbuilding Industry.

My final words: The naval architects, the marine engineers, the skilled labour, the unskilled labour in Europe equal very well those in the Japanese shipyards. When European Shipbuilders lose it is caused by politics and management weaknesses.
Regulation of Shipping - International or Unilateral
J.C.S. Horrocks

Abstract

Shipping is an international industry. All but the smallest ships are capable of worldwide trading and will visit many countries during their lives.

Vessels are bought and sold; they change their flag; they change their trading pattern. They must therefore be subject to a common regulatory regime if efficient shipborne commerce is to thrive.

One or two major casualties — Exxon Valdez, Herald of Enterprise — have threatened the common approach towards internationalism and the role of IMO.

The paper considers this development and the problems associated with the unilateral or regional regulation of shipping.

Shipping is an international industry. Although domestic coastal vessels and river craft have played an important role in national economies for millenia, it is in the development of trade between nations that maritime commerce has played such an important part. From the days of the Phoenicians to the dhows of the Middle East, from the great voyages of discovery of Renaissance Europe to the sophisticated trading patterns of today, shipping has opened up opportunities between nations the world over.

With the spread of trade came the need for port development and the establishment of facilities to handle the vessels which used them. In parallel came the need to treat visiting ships in a fair and uniform manner. Tonnage measurement for assessing dues for port and other purposes was an early subject for multilateral discussion and as long ago as 1873 an international agreement was reached on tonnage measurement — the Constantinople Convention: an agreement which, incidentally, is still the basis of the rules applied by the Suez Canal Authority for assessing the tolls payable by transiting vessels.
The international regulation of shipping may be thought to be a comparatively recent phenomenon, perhaps particularly in the area of marine pollution. But not so. The United States government, with European encouragement, called an international conference on oil pollution from ships as long ago as 1926, when the concept of prohibited zones for the discharge of oil residues was first agreed on a multilateral basis. The League of Nations took matters a stage further, developing a draft Convention on the subject in 1935, and only the Second World War prevented the convening of a conference which would have extended the international rules on pollution prevention to cover shipboard equipment.

The international regulation of ship safety goes back even further. International rules on the prevention of collisions and the development of a code of signals date from the 19th century, and the first safety of life at sea (SOLAS) Convention was adopted in 1914 following the loss of the Titanic. Two further versions of SOLAS had been adopted, in 1929 and 1948, even before the creation of IMO.

The relevance of this short history lesson is that even a century or more ago it was appreciated by the maritime states of the day that domestic regulation of an international industry was not only of limited value but could be positively prejudicial to the efficiency of maritime commerce. It seems, in fact, that even before the 19th century suggestions had been made for the creation of a permanent international maritime body - a forerunner of IMO - to take due account of the global nature of the shipping industry.

The reasons are not difficult to understand. A common understanding of the "rules of the road" and a common method for passing messages between ships and between ship and shore are two simple examples of basic needs. As maritime nations started to take an interest in the safety of their shipping, it was also desirable to ensure that the standards required of national flag tonnage were equivalent to those of foreign flag vessels plying the same routes, not only to ensure a comparable degree of safety for passengers and crew, but to maintain common ground for competitiveness between fleets. Even in circumstances where ships were on dedicated voyages between one country and another and bilateral agreements might in theory have sufficed, the attractions of wider international agreement, if only among the comparatively small number of active maritime nations which existed during the first half of this century, were widely recognised.

There were other reasons too. Ships were increasingly being built in countries other the flag state, requiring a common understanding of the design and equipment standards which they must meet. Vessels changed hands and changed nationality on the secondhand market, and both vendor and purchaser needed to know that design and construction standards acceptable to one administration would also be acceptable to another. It is no coincidence that the agenda for the first meeting of the International Chamber of Shipping in 1921 dealt heavily with issues on which shipowners from across the world wanted to
promote a common global interpretation - on load lines, on the sub-division of passenger vessels, on the carriage of deck cargoes, on life saving appliances and, importantly, on various legal issues - in order to ensure a uniformity of approach by administrations worldwide.

So when IMO finally came into being in 1958 the concept of an international regulatory regime for the shipping industry was fully accepted and understood, with international conventions already in place on ship safety, pollution prevention, load lines and collision avoidance. In the intervening years the pace of activity has increased considerably, but so has the membership of IMO. Once an organisation with a limited membership of more or less like-minded maritime nations, IMO is now a fully fledged partner in the United Nations system with 133 members.

Growth has certainly created some pressures: apart from IMO’s much publicised budgetary difficulties of the last few years, it now has to bring together a greater range of maritime backgrounds and yet still strive for agreement. A number of forces have been at play:

- the relative wealth of nations varies very considerably, yet the cost of compliance with most technical regulations varies little between nationality. Manning costs are the significant variable and in most countries they are no longer directly related to flag.

- Public and political opinion about the standards required of shipping has intensified in recent years, but to a different degree in different parts of the world. While the intensity of public interest ebbs and flows with the incidence of casualties close to home, matters such as passenger ship safety assume a greater importance in the public consciousness in Western Europe than in, for instance, parts of South East Asia.

- There has been a steady move towards the internationalisation of shipping, the growth of the open and second registers and the loss of a natural identity between the flag of the vessel and its country of beneficial ownership. The direct control of much of world shipping which the traditional maritime administrations used to enjoy has therefore been lost. As a result they have been keen to retain at least part of the influence they have lost as flag states by strengthening their role as port states.

Yet for all this, and in spite of all the differences which these pressures have revealed in IMO, the principle of developing shipping regulations on a global basis remains as sound as it ever was and, at least among the shipping community, largely unchallenged. The international process may sometimes be ponderous, and sometimes impatience creeps in. But it offers a level of certainty which an international industry desperately needs if it is to function in an orderly manner.
Let us look at a few instances of the problems that can be created in the absence of international agreement.

The prime example for anyone involved in shipping in 1992 has to be the US Oil Pollution Act of 1990 (OPA 90). The United States, it had to be said, has a long and, in industry eyes, undistinguished history of unilateral action in the field of shipping legislation. The pendulum of public and political opinion swings backwards and forwards, and in the early and mid 70s the United States and Canada were both prone to superimposing their own national regulations on foreign flag ships visiting their ports. Foreign vessels were inspected and sometimes found wanting for non-compliance with rules which neither the flag state nor international instruments required. There was a great deal of animosity, not only between the industry and the inspecting authorities but between many administrations and their Canadian and United States counterparts.

During most of the 1980s the mood changed. The need for international agreement reasserted itself, the US Coast Guard in particular became dedicated to the cause of international agreement, and the spirit of compromise for which IMO has become rightly celebrated, both within UN circles and beyond, was generally successful. The results were not always to the liking of the shipping industry and the rules were changed too frequently for the general good, but it was understood that international agreement must prevail. Even in 1984, when the Oil Pollution Liability Conventions were being updated by the adoption of Protocols, special efforts were made to accommodate higher US expectations of compensation levels in order to ensure that the United States could ratify the new instruments and thereby encourage international uniformity.

Then in 1989 came a dramatic catalyst for a change in attitude - a change which one must hope will only prove to be temporary, but is none the less damaging for that: the ‘Exxon Valdez’ ran aground in Prince William Sound off the coast of Alaska, creating a massive oil spillage. Political and public opinion hardened overnight and the oil and shipping industries have been trying to come to terms with the consequences ever since.

The US Oil Pollution Act of 1990 stems more or less directly from the ‘Exxon Valdez’ incident. More has been written about OPA than about any other piece of shipping legislation in living memory, probably since the beginning of time. Although the ‘Exxon Valdez’ was a modern vessel, well maintained and operated by the world’s largest oil company, the incident could not have happened at a worse time. The rehabilitation of the politics of the green movement and the general middle class upsurge in environmental awareness, growing public recognition of flagging out from the traditional registers, acknowledgement that the average age of the world fleet was steadily growing and increasing expressions of concern about the quality and level of competence of some ship’s officers after a decade of little or no training of seafarers in the
traditional maritime nations - all these factors combined to create a widely held view that "something must be done".

Many US domestic factors also contributed to the debate, not least the hotly disputed question whether individual US states should forego their right to legislate and fall in with federal statute and, importantly, whether the United States itself should compromise in order to fall in line with international agreement. One of the ironies of the power of the United States, which can exert so much influence in international discussions if it so chooses, is that the very size of its domestic market makes it remarkably parochial in its outlook. It is large enough to ignore the rest of the world if it chooses. While the Coast Guard may be fully aware of the compelling advantages of international agreement on the regulation of shipping, Congress has always been more inward looking, and there is no question that President Bush’s signing into law of the Oil Pollution Act in August 1990, despite his strong words of disenchantment at having to do so, was a very severe blow to the principle of international uniformity. It killed any chance of international adoption of the 1984 Protocols, which would have substantially increased the levels of compensation paid to the victims of oil pollution damage; it forced the hand of other nations on the question of oil tanker design; and it introduced new requirements on a range of other less striking but none-the-less important aspects of tanker operations.

But the purpose of this paper is not to analyse OPA 90 as such but to consider the relationship between international and domestic legislation, and in that context alone the act provides a valuable case study. Whether the industry likes it or not the importance of the United States as a trading nation is such that for most companies it is a commercial imperative to have the flexibility to operate into US ports. In practice, therefore, the United States is able to call the tune and others will have to follow. But if we accept, as we surely must, that the politicians and the regulators in the United States do not have a monopoly of sound ideas on measures for environmental protection, and that others are inevitably affected by decisions taken in the United States, the consequences of unilateral legislation look unappealing, not only for the shipping industry but for the world in general.

Consider oil pollution liability. Nobody disputes the argument that the victims of oil pollution damage must be adequately compensated, nor that ships must carry sufficient third party liability insurance cover to provide the required degree of protection. It has to be recognised that the atmosphere of litigation which has become a feature of the US courts in recent years has given rise to awards much higher than can yet be expected in other parts of the world. Indeed, as mentioned earlier, the limits of liability included in the 1984 Protocols to the 1969 Civil Liability and 1971 Fund Conventions on oil pollution damage were raised beyond the requirements of Japan or Western Europe, and certainly beyond those of the developing world, in order to meet US demands.
This was a price that administrations were prepared to pay in order to ensure an international agreement.

As we now know, those Protocols have been aborted because the United States, as a major importer of crude oil, was an essential part of the mechanism to bring them into force, and cannot now ratify them because the Oil Pollution Act is inconsistent with the international agreements, both in terms of its limits of liability and of the defences which protect the shipowner's right to limit.

The result is not only that the advantages to society in general of higher limits of compensation, agreed internationally as long as eight years ago, have been lost, but also that US citizens, who might themselves have been the beneficiaries of early compensation payments after a spill, in accordance with well established and understood international procedures, have been denied that possibility. They may, in due course, receive payments higher than would have been awarded under the international instruments, but almost certainly not without years of court hearings. It is not pure chance that the final settlement has only recently been reached in the 'Amoco Cadiz' case, which was taken to the US courts in the hope of higher awards rather than through the courts in France where the incident took place, but has taken 14 years to resolve. Can it really be in the interest of anyone that it takes 14 years to sort these things out?

The other major impact of the Oil Pollution Act is on tanker design. The double hull has its supporters and it has its detractors. It is now generally agreed that it will reduce the possibility of a spill in most circumstances but it is in no sense a guarantee against a major outflow. OPA 90 requires new tankers to be built with a double hull and introduces a phasing out programme for existing tankers. The rules apply, of course, not only to US flag vessels but to all oil tankers visiting US ports. The US legislation certainly accelerated international discussion on new concepts in oil tanker design in IMO. To that extent the determination of Congress to jump the gun, and decide unilaterally on the future of tanker design without the benefit of international discussion, has been effective.

But the more sober reflection which thorough discussion in IMO has permitted has led to international regulations that differ in a number of respects from the US legislation. For example, IMO has agreed, on the basis on extensive study, that the mid-height deck concept is an acceptable alternative to the double hull for new oil tankers. Will the United States now amend its legislation to fall in line with the international agreement? And for existing tankers, where the new internationally agreed rules concerning inspection and upgrading of oil tankers differ quite considerably from the US phase out rules based on vessel age, how will the United States respond? OPA 90 has undoubtedly heightened the profile of international debate on tanker matters but in the process it has created tremendous uncertainty, not only on the part of the tanker and oil industries but also about the degree of
support on which IMO can rely in its efforts to remain the undisputed source of the technical regulation of shipping.

On a smaller scale, perhaps, the aftermath of the loss of the 'Herald of Free Enterprise' off Zeebrugge in 1987 has created similar shock waves. The thorough debate on passenger ro-ro ferry stability in IMO which followed the disaster has revealed differences of opinion between administrations which, though not very significant in substance, have proved impossible to resolve to the satisfaction of all parties. The administration which seems determined to go it alone on this occasion is the United Kingdom, which has refused to be swayed by the views of other interested parties, notably the nations of North West Europe with whom the United Kingdom maintains regular ferry connections.

There is no denying the degree of public concern which stemmed from the loss of 193 lives in the 'Herald' disaster - though that incident was caused, of course, not by an inherent design fault but by a major operational error. Yet it may not be fanciful to suggest that the United Kingdom, always a staunch supporter of IMO and traditionally committed to the principle of international agreement, may have been influenced in its determination not to accept the consensus, whether subconsciously or otherwise, by the example of the United States on oil pollution questions. If so, it is a dangerous precedent which must at all costs be discouraged. Can it really make sense that theoretically different safety requirements apply to a ferry operation between Sweden and Germany, for instance, than between France and the UK? Or that French ships should be obliged - as may happen - to fall in line with British thinking which the French administration does not endorse?

There is one other concern which must be addressed and which poses yet another threat to the role of IMO, and that is the danger of regional agreements. There is little question that the European Commission would like to claim unto itself greater authority on technical and operational matters than it has so far achieved. As yet the members of the European Community have by and large acted individually in their discussions at IMO and the maritime administrations of the 12 member states would surely be reluctant to have to defer to a Commission spokesman to speak on their joint behalf. But the European Community, which will be enlarged in coming years, does now offer an established means of co-ordinating the views of the member states and it must be expected that there will be growing pressure to agree a European "party line" in advance of IMO meetings. The logical and dangerous next step is that, if that agreed party line is not accepted by IMO, there will be pressure from the Commission for Europe to act regionally, on the grounds that the Community view represents the collective wisdom of Europe as a whole. At the very least, it must be anticipated that the Commission will try to regulate in areas where IMO has decided to leave detailed decisions to individual administrations to resolve.
While this may sound unobjectionable, the growing importance attached to port state control makes it more, rather than less, important that there is a clear global understanding of the rules with which ships must comply. Disagreements in national interpretation of the international rules can generally be resolved, either by referring back to IMO or bilaterally. If regional interpretations are allowed to take root they are bound to assume an authority which can only undermine the sanctity of global agreement through IMO.

So where does that leave us? The international nature of the shipping industry has in no way diminished in recent years. On the contrary, the widespread use of foreign flags, of foreign crews, of third party ship management companies and the general trend away from the traditional relationship between the owner and his national flag state make the need for international agreement all the more compelling. The old arguments that a ship needs international agreements to ensure that it will be equally acceptable in Argentina and Australia, in Belgium and Belize, are as strong as ever. But today we also need a global understanding on acceptable management standards, on the obligations on the flag state and on a broader range of issues than was previously the case. Nothing could be worse than for administrations to adopt a policy of short-termism and to follow the example of those states who have decided that, because they cannot achieve instant agreement at IMO, they will go ahead anyway and introduce their own requirements at either domestic or regional level.

International agreement may imply compromise, but compromise does not imply weakness so much as recognition that maritime trade can only function efficiently if the rules are adopted at an international level.
The role of government in marine safety
A.E. Henn, R.F. Viera

ABSTRACT
The role of government in marine safety has traditionally been viewed as one of regulator or oversight control. The understood purpose of such control being safety of life and protection of the environment. Today, however, labeling the government's role as one of regulator is a gross simplification. While it is true that the development and enforcement of safety rules constitutes part of a government's work in marine safety this paper shows how regulations are just one way in which it seeks to promote marine safety. The responsibility for marine safety lies with several parties. Vessel owners and operators, flag administrations, port states, classification societies, and insurers/underwriters all have a specific role and responsibilities which must be met. Regulations alone cannot assure that an adequate level of safety is maintained. The roles and responsibilities of the various involved parties can overlap and appear to be conflicting at times. Frequently, government must serve as a unifying link between the affected parties. Experience has shown that the promotion of mutual cooperation and the identification of commonly held goals is the best approach to use in accomplishing governmental mandates. From this, clearer delineation of responsibilities can be made. This paper outlines both the pragmatic duties of government and the less obvious responsibilities implied in carrying out these duties to their logical conclusions.

INTRODUCTION
In order to fully appreciate and understand the role of government in marine safety some historical perspective is necessary. Since the early days of commerce the transport of goods by water has been recognized as an effective and prosperous means of conducting trade. However, the hazards associated with
ocean shipping quickly manifested themselves and the position of underwriters was firmly secured. Classification societies then came on scene as a means of resolving conflicts between the owner and underwriters. It is correct to say that the concern for marine safety largely predates any government role. Because of the unique assortment of interests which impacts on the maritime industry the role of government in marine safety is unusually complex when compared with many other regulated industries.

Regulation of shipping was first seen in the form of domestic legislation by the mid 1800s, for their own vessels in their own waters. No international efforts were visible until 1913 when just thirteen countries (although they were arguably the thirteen countries which essentially constituted merchant shipping at the time) met in London to discuss the tragedy of the TITANIC. Sixteen years later SOLAS 1929 became the first truly international effort to improve marine safety. The role of government must be examined within the intricate relationship of regulatory bodies, insurers and owners/operators which has developed over the years that provides the framework in which the maritime industry operates. It is a dynamic role distinguished by a multinational character which is constantly changing while seeking to maintain long standing maritime relationships. The commonly held viewpoint of governments being "regulators" oversimplifies their responsibility and overstates the obvious.

PARTIES INVOLVED IN MARINE SAFETY

One interesting and particularly important aspect in marine safety is the large number of parties which have a vested interest. A list of parties must include; governments (flag administrations and port states), ship owners and operators, insurers (both hull underwriters and protection and indemnity clubs), labor unions, shipbuilders, classification societies, cargo interests and various trade or specialty groups. Some argue that the interests of the parties are often naturally opposed to each other. Also, with such a diverse and wide-ranging breadth of involved parties it would seem that there should be enough "safety nets" to catch any problems. In actuality, an interdependent relationship exists between the parties. A few examples are:

- Flag administrations and classification societies: Almost no flag administration has a sufficient number of qualified personnel available to perform all the duties required of it by various International Maritime Organization (IMO) conventions and national legislation. Help has traditionally been sought from other organizations. For example, load line assignment is a task commonly delegated to classification societies along with the issuance of SOLAS safety certificates and IOPP certificates. Furthermore, in many cases administrations use the expertise and experience found in classification societies rules by adopting
them as their standard for ship construction. Classification societies can be thought of as subcontractor playing an important role in filling out "gaps" in an administration's infrastructure.

- Classification societies and insurers: Perhaps no relationship in the maritime industry is older than that which exists between classification societies and insurers. Classification societies originally helped resolve the conflict of interest between owners and underwriters. Today, as noted above, classification societies serve in a much more broader capacity. But the original basis still exists, that is, providing a form of risk management for the insurers.

- Flag administrations and vessel owners/operators: In addition to the well established regulatory relationship between these two parties, Flag administrations also perform a more subtle but nevertheless important function involving business matters. A definite trend towards the adoption of international rules and standards has become more common over the last thirty years. Flag administrations must help ensure that the pursuit of standardization does not create an unfair economic disadvantage for its shipping industry. This responsibility is in part evidenced by actions taken by a government to ensure that all vessels calling at their ports are meeting the same level of compliance as their own vessels.

Several observations are appropriate at this point.

- The emergence of IMO as a forum in which to develop and agree upon international standards for marine safety is a particular valuable asset which must continue to be fostered. In particular, IMO facilitation of cooperation between parties on technical matters and distribution of that information must continue.

- The interdependency of involved parties described above is firmly in place and is unlikely to change soon.

- The government is one of several integral players in the system which affects marine safety. Therefore, it is vital that the various players realize their full potential.

Experience has shown that the promotion of mutual cooperation and the identification of commonly held goals among the involved parties is the best approach for a government to use in accomplishing its legal mandates. From this a clearer delineation of responsibilities can be made. Government is often in a unique position to act as a common link between the parties. Sometimes overlapping, and on occasion, conflicting objectives may occur in the parties. Even if it is not always clear what the parties respective responsibilities are it is abundantly clear that they all have some role in the safe
operation of vessels. This must be the point of departure for all future discussions. But where voluntary cooperation and compliance is not forthcoming it is the clear duty of the administrations to impose sanctions where appropriate.

QUANTIFYING MARINE SAFETY

In trying to quantify marine safety, or safety in general, one must discern between absolute safety (i.e. the state of no accidents and loss of life or property occurring) and the goal of achieving an acceptable level of safety. Ships can always be built stronger, inspections can be made more often, and additional rules can be imposed. Pragmatically however there is a finite limit as to what can realistically be done to improve material conditions aboard ship. For example, ships can be made tremendously strong but given a big enough rock they will still split open. It is therefore incumbent that the involved parties seek the most effective combination of factors that will improve marine safety. It is a harsh observation for a technical organization to make, but regulations addressing only material conditions will not guarantee an acceptable level of marine safety is achieved. The logical corollary of this statement is that government must perform a role of more than just regulator, if it is to continue to improve marine safety.

One goal of government is to promote marine safety with the objective of reducing casualties while seeking to minimize the adverse consequences which may occur. Two problems present themselves in efforts to quantify marine safety.

- How do you measure success? If success implies the effectiveness of rules, regulations, etc. then data must be collected to demonstrate this.

- Even with accurate statistics it is often difficult to assess and compare accident data. For example, a simple grounding can be a catastrophic event on one occasion while an insignificant event on another. How much effort is appropriate in trying to prevent groundings?

Human factor concerns are being given increasing recognition in terms of preventing accidents. In this regard, the United States has placed more emphasis on casual factors that impact on a vessel's safety record. Causal factors include, company management practices, maintenance records, overall safety philosophy, crew training and the vessels service and trade. The use of Critical Area Inspection Plans on tankships and the adoption of IMO resolution A.680(17) are both examples of this change in direction and approach involving marine safety. However, the collection of casualty and inspection data is an area that offers great promise as a means to improve marine safety.
DEVELOPMENT OF SAFETY REGULATIONS

Historically, the United States, as many countries, has seen a reactive approach being taken in regards to marine safety. Reactive because laws affecting marine safety were enacted as a result of a casualty rather than employing a rationale or analytic method to anticipate needed regulations. Accidents are often highly visible events pointed to as evidence of declining safety. The purpose of regulations is to provide a minimum acceptable level of safety. Regulations cannot easily embody every aspect impacting on marine safety. And of course, the realities of the situation means incentives for compliance or noncompliance have to exist.

Two current methods used in the development of regulations are;

- The use of "round table" discussions among subject matter experts is a proven and reliable way of developing regulations. When a general consensus can be found the result is usually a sound one. IMO is an example of this method.

- When it is possible to explicitly identify a goal a more scientific approach is possible. A scientific approach involves a formal problem definition in terms of identifying what needs to be improved, quantifying it in terms of cause and effect, and developing possible solutions to the problem. There will, of course, always been some element of judgment involved.

Governments are faced with the dilemma of a "no-win" situation when it comes to regulations. If a casualty occurs the public asks... why wasn't there a rule to prevent this from happening? On the other hand, if government proposes a rule in the absence of overwhelming evidence that such is needed they are accused of over burdening industry. Additionally, the role of regulator is an easy one to criticize. Accusations of regulators being bureaucratic, lacking of any appreciation of profit considerations and being the creators of unnecessarily expensive changes are often heard. Governments are therefore enjoined to work in close cooperation with maritime interests in developing regulations. Another concern with regulations is that they are often vessel performance oriented rather than applying a specific set of maintenance procedures which must be followed (this is particularly noticeable when examining the difference between regulations in the marine and aviation industries). In addition, when regulations are made specifying a particular standard the result is sometimes a rule which can become technologically outdated or overly restrictive for the ship designer. Such impediments to the adoption of new technology ultimately harms the flag states own carriers more than anybody else. For this reason, government must strive to constantly update and revise regulations. Nevertheless, regulations provide that "all important benchmark", which is necessary in identifying substandard performers. The use of regulations to achieve an
acceptable level of marine safety is a difficult and complex effort but the alternative, no regulations, is clearly worse.

Domestic legislation activity can sometimes cause a redirection in efforts, an example is the United States Oil Pollution Act of 1990. Certain provisions of the Act severely limit the ability to develop regulations which are in consonance with international standards. An effort must be made to develop standards through IMO whenever possible but if government properly perceives progress as being too slow the responsibility to protect its interests may have to take precedence.

Fortunately, many positive changes have been made, especially in the last twenty years. United States regulatory efforts have seen a shift from an emphasis on domestic regulations to an emphasis on development and recognition of international standards. One useful change in the United States has been a movement towards either adopting industry standards within the body of our regulations or simply incorporating by reference an existing industry or IMO standard. A valuable feature of IMO is the pooling of ideas and thoughts which have materially improved ship safety through the sharing of the latest design techniques and operation approaches. The development of numerous IMO codes such as the Gas Carrier Codes, Bulk Chemical Codes, International Maritime Dangerous Goods Codes as well as several important conventions, Load Line - SOLAS - MARPOL, has been remarkable. The contribution that IMO has had on marine safety since its establishment in 1958 is noteworthy. IMO is unique in its ability to react quickly and decisively when clear cut changes are needed. Recent examples of this trait include heightened stability requirements prompted by the Herald of Free Enterprise, MARPOL changes in response to the Exxon Valdez grounding and various initiatives involving bulk carrier losses.

The increasing involvement of professional organizations is another area that holds great promise. The International Association of Classification Societies (IACS) is a valuable partner in the promotion of marine safety. It continues to offer suggestions for improvements in safety standards, providing input for the interpretation of conventions and resolutions in its IMO consultive status, and as liaison for the exchange of information of views and information of interest to class societies. Other organizations performing similar roles include the Baltic and International Maritime Council, Oil Industry International Exploration and Production Forum, International Maritime Pilots' Association and the Hellenic Marine Environmental Protection Association.

SPECIFIC DUTIES OF GOVERNMENT

Given the foregoing it is now possible to describe some of the more pragmatic duties of government in promoting marine safety.
The United States Coast Guard is mandated to save life and property at sea and to protect the marine environment. In doing so it performs the following functions:

- **Flag administration:** This involves carrying out certain duties specified in numerous IMO convention instruments as well as domestic work. In order to do this task effectively it requires an objective and stable regulatory framework. Unfortunately, not all governments have an adequate infrastructure in place to exercise their convention responsibilities.

- **Port State:** Governments must take steps to verify that visiting foreign vessels are safe to proceed to sea and to ensure they are meeting the same international as well as domestic standards, if more restrictive, as their own vessels. This is especially important when the foreign ship's flag administration is unable to perform their duties. Port state action then acts as a form of "safety net".

- **Casualty investigation:** Although casualty reporting to IMO is a responsibility of flag states it is decidedly in governments best interest to have an aggressive and extensive casualty investigation procedure in place. Through casualty investigation, and the valuable statistics which come out of it, lies the key to earlier identification of problems with the opportunity for assessment and proposal of solutions. One must recognize that opposition to casualty investigations exists out of fear of penalties/fines and damage to company reputation.

- **Facilitation of commerce:** Public safety and environmental protection is, and must remain, of paramount importance to government. However, government should balance proposed rules and regulations against cost and viability. As noted above, regulations can serve as an effective technological impediment to progress. Government must be open and receptive to regulation changes that recognize advances which improve productivity or efficiency while maintaining the desired level of safety and environmental protection.

- **IMO Interface:** Government must represent the interests of their shipping industry and the public at IMO. The value of having such a widely recognized and effective forum as IMO cannot be understated. If current trends towards the development of international standards continues at its present rate this particular role cannot help but become increasingly important.

- **Regulator:** As described above, government occupies the role of regulator for domestic legislation and implements IMO instruments.
SUMMARY

As means of summary and to highlight several important future goals for government in marine safety the following points are offered:

- A concentrated effort must be made to improve sources and means of collecting casualty and performance data. Through this a more scientific and rationale based approach can be developed for improving marine safety. Particular emphasis should be given on the effect of human factors. This will also lead to more technically sound regulations and help identify outmoded ones.

- More joint ventures must be fostered between the various parties involved in the marine safety equation. The parties must draw on their respective strengths in correcting deficiencies in our present system. By working together more effectively we are in a better position to move ahead on our common goals.

- Sharing of information between port states can help reduce substandard performers. No matter how high the standard is raised it is of little value if some mechanism is not in place to identify those substandard performers who manage to go under or around it. We all must equally share in our responsibility to marine safety.

- Research programs are a key element to developing a scientific approach to marine safety regulation formulation.

- Standards for flag states must be developed. Without a sufficient infrastructure in place to ensure implementation of IMO conventions problems will continue.
The view of a classification society on the changing shipping scene

R. Kruse

ABSTRACT

A Society's 125th Anniversary seems to be an appropriate occasion for viewing the role of classification in the changing shipping scene. Such an event gives reason for looking back on the past and for position finding. It is not a matter for this most topical conference to view the past. However, it should be mentioned that at least during the past 150 years, the technical development has permanently brought its influence to bear upon the shipping scene. Owing to the steady development of steels, construction methods, machinery and, lately, the introduction of electronics, ships nowadays are among the most sophisticated products in our highly technicalized world. The classification society has at all times been actively involved in this process and played a dominant part. The idea for its foundation by shipowners and underwriters among other aspects was that the safety concepts for ships were to be developed and their introduction supervised by the classification society. As far as newbuildings are concerned, this necessarily leads to rules and regulations being worded such as not to obstruct new developments. The technical possibilities available have to be integrated and, following the principle of equivalence, it must be possible to also realize unconventional ideas.

This demonstrates that within a changing shipping scene, the classification of newbuildings does not present any problems. To mention only a few examples: safety concepts for a high degree of automation are developed, taking into account the whole range of technical possibilities available. This then results in a reduced number of crew as stipulated by the industrialized countries. With the aid of modern computation methods, it is possible to adapt ship design to all kinds of requirements. Also, it is possible to apply optimization programs, e.g. for the stowage of 11 containers athwartships below deck in a Panmax ship. Optimization of the new double skin tankers does not cause any problems.

The situation is different, however, regarding the attendance to the fleet in service. It proved that owing to the steadily increasing average age of, in particular, bulkers and tankers, the conventional survey procedures were no longer adequate, as in older ships, the inspections required to be carried out in the course of a class period occasionally left undiscovered certain corrosion damages, signs of fatigue, etc. This resulted in an increasing number of failures of these ships.

Since mid-1991, the classification societies associated in IACS have been taking these facts into account by amending their rules accordingly. Also, in their specific instructions to the surveyors, they mentioned all possible weak points, and fixed details on admissible corrosion limits. By introduc-
ing an additional auditing procedure, GL have assessed the condition of all older ships of these damage prone types and in some cases initiated immediate action for restoring the required safety level.

The accidents having occurred during the past few years have meanwhile induced IMO to intervene in the determination of hull survey scopes. In this regard, the IACS rules at present in force are once more being revised. The results of these efforts will then presumably be passed as an international regulation. The flag states will then be ultimately responsible for ensuring that these regulations are duly observed. If authorized by the competent authorities, the classification societies then have to carry out the relevant surveys on their behalf. It will be essential to avoid duplications of surveys.

We very much regret this development, much more so as with the majority of ships the classification rules are duly observed, thereby absolutely safeguarding the safety of old ships as well. Only some few ship managers and ship operators do not observe the regulations stipulating that in case of any problems arising which may affect the vessel’s class – such as corrosion or cracks – this will be remedied in cooperation with the classification society. A few make the vast majority suffer!

In general, it can be stated that the majority of accidents (i.e. 80% or so) are attributable to human failure. This means that for achieving a higher standard of safety, it will not be necessary to introduce new rules and regulations; rather, the existing ones will have to be observed more strictly. It is intended to ensure this by introducing quality assurance systems. As a first step, the management firms associated in the International Association of Shipmanagers decided to introduce a relevant Code defining all steps to be taken for ensuring reliable attendance to ships. This system is then assessed and certified by impartial auditors. Following the necessities of the market, such procedures have already been introduced by shipowners as well. The procedures also duly take into account the classification requirements. The classification societies expect that the routine checks will ensure that their requirements will in future be observed more carefully.

Within IMO, too, regulations are at present being prepared. For some years now, IMO has been publishing non-binding management guidelines for the safe operation of ships and for pollution prevention. A new Chapter of the SOLAS Convention is now intended to be introduced for operational aspects to be covered, with details specified in a mandatory code. The systems are based on the ISO 9000 series. This enables a large variety of activities to be listed systematically and instructions to be given for their strict implementation.

The classification societies associated in IACS, too, have declared the introduction of such systems to be binding. Although in the proper sense, classification is quality assurance, this system is intended to enable the whole range of activities performed to be audited as to completeness, quality and performance. This audit is then preferably to be performed with the participation of IMO and the international underwriters’ associa-
tions. The certificate issued following the audit shall demonstrate to the flag states, among other aspects, the quality of the work performed on their behalf. This could well replace the previous procedure of checkings with the classification societies by the individual states. The objective is to restore the confidential relationship between the classification societies and the flag states/underwriters. For them to cooperate with and rely on the services of the classification societies continues to be necessary as only the classification societies maintain a worldwide network of surveyors capable of meeting the increasingly more exacting demands. It will thus be possible by one single survey to cover the interests of all concerned: the flag states, the insurers, and the classification societies.

With this in mind, it will also be necessary to harmonize the different classification societies’ standards. These efforts will have to be coordinated by IACS, where unified requirements are formulated, experience is exchanged and joint approaches are discussed for dealing with unreliable shipowners. This includes procedures to be applied in the case of changes of class, as far as the observance of recommendations is concerned.

Beyond this, within IACS, unified standards are established for the implementation of flag state regulations. This alone will ensure an equal treatment of all ships by the different societies.

Regarding the cooperation between the classification societies and IMO, it may be stated that IMO sets basic standards for ship design, e.g. the introduction of double skins for tankers. Subsequently, the classification societies will determine the structural details, including the dimensioning of the structural elements, in accordance with their own rules. It remains to be seen to what extent IMO will include the classification societies’ safety philosophies in its discussions. Thereby, it would for the first time enter the domaine of the classification societies. Considering the past experience, such a step is not required, as all IACS classification societies are fully aware of their responsibility in performing these functions and as the basic principles for them have already been harmonized within IACS. Any further details introduced on the statutory side would hamper the versatility required for continuous progress in technology.

As far as newbuildings are concerned, classification has become increasingly important. Many shipyards try to meet the requirements with a minimum staff of engineers by having complex computations and research activities performed by the classification society. As a result of this division of functions, considerable progress has been made in the handling of sophisticated ships. For Germanischer Lloyd, for instance, strength analyses of hull structures and the calculation of global and local vibrations are among the routine optimization processes for new ship types: considering their high propulsion powers and the extreme locations of their deck houses, in particular, prognostics on vibrations are an absolute necessity. Later corrections by the trial-and-error method are much too expensive.
An approach to sound management of the marine environment

J.A.C. van Rooij

I should like to speak to you today on finding solutions to challenges. Challenges that are indeed waiting in ambush NOT for US, but for generations down the road.

I should like briefly to mention Greenpeace and its objectives. I will mention some of the key issues and some practical ideas. To protect the interests of all users of the seas.

But most of all about the creation of the ideal atmosphere in which the challenges of the future will be addressed. An atmosphere not of accusation and blame, but of constructive dialogue and cooperative efforts. And I will conclude with my hopes for the future.

May I first say how happy Greenpeace is that such a concentration of competent maritime minds is present at a conference that has safety of the maritime world at heart.

I wish you well in all your deliberations in the many individual sessions this week.

And may I humbly offer congratulations from Greenpeace to the University of Delft on its impressive 150th anniversary. It has achieved the position of perhaps the premier technical institute of learning in the Netherlands, and a respected name throughout the world. An impressive achievement, and I hope the next 150 years will be as productive as the last 150.

Firstly a couple of words on Greenpeace. I have no doubt that Greenpeace has made sufficient noise on the world stage over past years that you will have heard enough of it. But I hope you have not been OVERexposed. That only diminishes the value of our messages. May I emphasize that we have made this noise NOT for OUR OWN good... but for what we believe is the good of ALL OF US.

Greenpeace International is now 20 years old. We have 4 million contributing members worldwide, of which, I am proud to say an amazing 20% in the Netherlands.

I am led to believe that this is due to the Dutch always enjoying telling other people what to do.
Greenpeace has 26 national offices around the world and is proud to operate 8 vessels worldwide. It remains one of the last international bodies to be absolutely independent of any external vested interest.

What has Greenpeace achieved over the past 5 years? Plenty of attention, awareness, concern, and across all levels of the population. May I just mention one success - the Antarctica Treaty, valid for an unheard of 50 years, signed last year by 40 countries, in which Greenpeace was undoubtedly the primary driving force.

But considering the short amount of time we have here today this is neither the time nor place to sell Greenpeace. It is the ideas I want to sell.

You will all know that in two days time the so-called Rio Earth Summit will commence. International policy makers will seek to agree a worldwide policy to protect our threatened environment. We hope that we will achieve more here in Delft, than that will be the case in Rio.

Twenty percent of the world's ocean pollution comes from sea-based sources. Eighty percent from land-based sources. We have some hard work here in Delft too.

Our mutual concern - the sea and the environment.

I do not have to detail why Greenpeace should be so interested in the health of the Sea.
We need the sea. And today, the sea needs US.

The sea needs the technical competence of naval architects, shipbuilders, trading companies, environmental experts, in one word YOU.

Before I address some specifics of the maritime environment one more thing.

May I compare air and maritime traffic.

The systems of air traffic control, safety, and technical verification that ensure the safe and efficient operation of air travel are highly sophisticated and in general very effective. And yet the air transport business is at most 90 years old.

The maritime industry is over 2,000 years old, and yet it has nothing of the same level of safety and technical verification systems as the air transport industry. Why it that? Probably because we have always taken it for granted.

I think you will agree that today that is no longer possible. The threats, dangers, risks and costs of failure are now so high that I believe we must apply the same level of discipline to sea traffic as we do to air traffic.
May I address only three of the many issues: oil tanker design, nuclear transport and operational discharges.

Firstly tanker design. Oil is still critical to us. It has played a dominant role in the economics and politics of the 20th century. And because consumer markets are generally far from producing areas, most of it is transported by sea. Projected environmental damage shows that continued reliance on oil will result in a grievous assault on the marine, terrestrial and atmospheric environments.

Spills, discharges and accidents must be reduced for all our safety. Firstly we must take steps to ensure the environmentally safer transport of oil. At the same time we must reduce our dependence on it. It will require great determination, imagination, and a willingness to compromise.

Despite international efforts oil spills are on the rise. One major reason is vessel age. Older vessels fail more frequently. Now surely is the time to institute and enforce stricter design and construction requirements for safer oil transport by sea.

We recognise that much work has been done, but we have to recognise also that the experts disagree... and often. I wonder if this conclusion can only be explained by the continued presence of prejudice and the promotion of vested interests. Our world at least deserves honesty.

We must make sure that oil tanker design is upgraded to the point that oil spills are infrequent enough not to catastrophically affect our precious environment. We should become pro-active and not stay re-active.

In a recent Greenpeace position paper on tanker vessel design we have pleaded for many specific measures. Many of you already know them. I will not mention them here. They are designed simply to raise the safety of vessels in use. Improving the design of new vessels and accelerated phasing out of out of date vessels.

The success of these safety programmes will be a function of the cooperation between all concerned parties.

On the subject of nuclear transport. You will probably know there are at least 10 atomic bombs or nuclear power plants on the bottom of the world's oceans. And what is now being discovered in Russia and Eastern Europe simply defies the imagination. Victims of accidents and mishaps that should not have happened, and frightening problems for our future generations to solve.

As the nuclear industry develops so will the requirement of reprocessing of INF, irradiated nuclear fuel. There are a limited number of reprocessing sites worldwide and transport from client to reprocessor takes place often by sea.

Current regulations permit vast and hugely radioactive shipments to be carried on vessels that have hardly any special precautions
As in the transport of oil products, INF has the potential for being very deadly indeed.

Let me give you an example of the difficulty of regulating an activity as international as shipping. The International Atomic Energy Agency has promulgated testing criteria for casks used for transporting INF. In the view of Greenpeace, ... and maritime bodies such as the IMO, certain of these tests do not respond to the very real dangers of sea transport.

Even the experts disagree. We are pleading for a more open and objective consideration of all such complex problems... with less weight given to vested interests.

Greenpeace believes the current state of affairs calls for even more extreme measures than those proposed by the IMO, and these are already beyond those of the IAEA. We believe the IMO should require the IAEA to undertake tests to demonstrate cask integrity in worst-case scenarios.

And we feel that, because we have proved the transport of INF is simply not necessary, member states should not allow its further transportation.

Operational discharges from ships.

On the subject of certain of the penalties for illegal discharge Greenpeace finds it strangely illogical that many of these may fall under a vessel's insurance regime such that an owner can claim them back from his insurer. Surely we shouldn't be having all premium payers paying for the sins of a few.

Also Greenpeace feels that the 'Polluter Pays' principle should be applied with more vigour and consistency.

A recent evaluation of the application of the discharge provisions of the MARPOL Convention of Friends of the Earth, Seas at Risk Federation and the Dutch North Sea Working Foundation focused on two issues: the adherence to reporting requirements, and the level of enforcement.

Let me quote from the evaluation report.
- "Reports lack important qualitative and quantitative information."
- "Incomplete reporting is common."
- "Since 1987 only 7 alleged chemical discharges have been reported."
- "Since 1988 only two, TWO MIND YOU, contracting parties have reported discharges of garbage."
  (If it was not so tragic it would make you laugh.)
- "Information submitted allows for no reasonable conclusions to be drawn."

Considering the information sources and integrity of the authors the credibility of the report must be regarded as very high. The
conclusions to it are at the very least most disturbing.

Incomplete reporting at numerous different levels allows only one conclusion to be drawn from the study. If we assume that signatories should be telling the truth, the whole truth and nothing but the truth, then every one of them is committing perjury. Lying either deliberately or as a result of negligence. The determination and will is not there to ensure proper complying with the convention.

If this is the commitment that the world and its people's can expect from governments and contracting parties to these Conventions then one may be forgiven for thinking there is not much hope for any of us.

This brings me to the subject that some humorist popularised as 'Greenwash'. This is the process whereby trans-national companies are preserving and expanding their markets by posing as friends of environment and leaders in the struggle to eradicate poverty.

For example:
- A leader in ozone destruction is taking credit for being a leader in ozone layer protection.
- A giant oil company professes to take a precautionary / approach to global warming.
- A major agrochemical company trades in a pesticide so hazardous it has been banned in many countries while saying it is helped to feed the hungry.
- A major port may introduce the concept of 'the Green Award'.

See through the sham. The power of advertising is being directed at greenwashing many sinners. In some days time it will be going global with the TNC's (transnational corporations) participating in the Earth Summit in Rio. With the cooperation of governments and leaders in the United Nations TNCs are working to CONTROL the definition of environmentalism and sustainable development to their own ends.

We have the responsibility to ensure that the global greenwash that UNCED is promoting is not seen as a solution to the world's environmental problems.

There are so many powerful vested interests in the world that the battle for justice and a balanced and responsible development will be a big one. And the price our grandchildren will be asked to pay may just be beyond them. NO, they won't be ASKED to pay it. Sooner or later they will HAVE to pay it. They may have no choice.

I hope we will be able to save them the effort. It will be a function of team work. Working together without being bullied by powerful vested interests that only have the profits of today in mind.

And working together at such a level as today. Where policy
makers and technical minds can address problems in an atmosphere of reasonableness. There is currently insufficient contact between them. We should help the process along.

Greenpeace offers you every best wish and support in your efforts to build safer vessels, and regulate their operation with greater responsibility. And in making the seas and our environment a safer place.
The role of the Royal Netherlands Navy

R.M. Luijse Schipholt

Introduction

Not surprisingly the Navy is not immediately associated with safety and environment at sea. Gunfire and sinking ships spring more to mind. But of course since more than the 500 years of it's existence the Netherlands Navy assured the safe and unobstructed freedom of the seas as advocated by Hugo Grotius.

That the experience and means of our Navy are also used to rescue people at sea in peacetime is widely accepted without realising the efforts and organisation that lies behind this task. While at least five ministries and as many volunteer societies are preoccupied with dividing among eachother the coastguard duties of ensuring safety along our coast, the coordination of disaster relief when, say, a ferry sinks, is left to the Navy and the evacuation of victims to our naval helicopters. At those moments it is afterall effectiveness that counts.

Also the clearance of mines at sea, in peace and wartime is of course a task of the Royal Navy. And that this task of safeguarding navigation at sea is still continuing, also in our waters, is shown by the regular catch of mines by our minehunters or fisherman. It is mostly the task of our underwater demolition teams to disable these dangerous souvenirs of the past that land in the fishnets. For that purpose the Navy runs a very specialised diving school and dive medical centre.

Some areas of naval activity in the marine safety field warrant some special attention, in view of the interesting technical features they have. The first one is hydrography, a special task of the Royal Netherlands Navy. In particular the modern developments in data acquisition and (sea)mapping will be described.

Secondly modern naval practices in training for safety at sea will be explained. Our own training school, with the most modern training aids, prepares our personnel for damage control and repair at sea. A subject which is, with the increasing danger for our environment of oil and chemical transport over sea, while crew size and expertise are shrinking, of vital interest to all marine engineers.
Lastly some specialised fields of technical know-how in the Royal Netherlands Navy will be highlighted of more general interest to all marine engineers involved with marine safety. These technical investigative results stem from damage-analysis and prevention studies associated with the typical wartime tasks and environments of our ships i.e. withstanding battle damage and sometimes extreme pressures and stresses, high speed and excellent seakeeping under all circumstances. This has lead to advanced calculations of strength and stability but also to hydrodynamic and control engineering solutions which might well have direct applications in a wider maritime field.

**Bathyscan seamingapping system**

The Hydrographic Service of the Royal Netherlands Navy has realised for quite some time that a much higher density of depth measuring points of the seabed is necessary, especially in certain areas of the North Sea, in order to satisfy the much higher sea chart accuracy requirements of today and tomorrow. This in view of the bigger draught of modern ships. This would require with conventional echosounding equipment, a considerable increase in capacity or numbers of hydrographic ships. This was for practical and economic reasons not feasible and the decision was taken in 1988 by the Navy to acquire equipment that could take depth measurements in the sea over a wider path.

There are basically two techniques for obtaining this bathymetric information over a wide path. Most systems are so called multibeam systems with a number of transducers mounted in parallel in a banana shape. Mostly these are hull-mounted transducers under the ship. The total pathwidth to be obtained with this type of system is about 2.5 times the waterdepth. Depth measurements have in this case a spacing of about 2 meters.

Another technique as in the Bathyscan chosen by the Royal Netherlands Navy, is the interferometric side scan sonar. The basic principle of this system is the measurement of phase shift of reflected sonar transmission by the "target" by two transducers at a small distance apart. By using a multitude of interferometers the Bathyscan can measure with great accuracy the angle of reflection from the seabed in relation to the vertical. Since the distance to the seabed is a function of reflection time and the known sound propagation characteristics in water, the water depth and seabed shape can be accurately measured over a wide area.
In the system used by our Navy the transducers are mounted in a body towed through the water at a depth of 6 meters alongside the ship. In order to obtain an angle measurement accuracy of 0.2 degree, on both sides of this "fish" multiple interferometers are mounted. One transmitter and four receivers on each side to be exact. The reasons for us to select a technique using a towed body are: ease of maintenance, transportable, replacement is possible, and the "fish" can be towed under a thermocline layer.

The data acquisition system in the "fish" sends 300 KHz pulses alternatively with port- and startboard transducer. Also mounted in the towed body is an echosounder and sensors for measuring roll, pitch, wave motion, course and depth of the "fish". The reflected pulsesignals are received by the interferometers and transmitted with the other sensor signals through the towing cable to the ship. The interferometer signals, corrected and using the other sensor data, will be transferred to distance and angle data of points on the seabed. About thousand depth measurements in a second are recorded with the associated positions. The ship position is also accurately recorded in the Bathyscan system. This ship position will later during data analyses be transferred to the actual "fish" position correlated with the appropriate seabed measurements of the towed body. The depth, corrected for roll, pitch and wave motions will be presented graphically on a colour VDU as a seabed presentation. Apart from the seabed shape presented as a change in colour, with a resolution of 1 meter, the motion sensors can be continuously monitored on the screen. Built-in test equipment will transmit automatically system faults.

The collected data will be worked out in the processing system in a square network of depth information, the squares being five by five meter. The depth, with a resolution of 0.1 meter for each square, will be determined by averaging the about 30 validated depth measurements of that square. From this basic and accurate depth information various endproducts can be automatically produced such as: depth charts on a scale 1:10000, magnetic tape with all recorded depths or a selection there off and a 3D plot as quality control.
It is obvious that the amount of data recorded with this new system is immense compared to the old depth measuring system. For example, 2000 signals are transmitted per "ping" of the sonar. These signals with the associated distance values and other sensor data are filtered by the pre-processor in order to eliminate undesirable peaks.

Then depth data will be generated with a horizontal interval of about 0.5 meter. The resulting data of about 7 Mbyte per hour will be stored on magnetic tape. Data storage takes place on a commercial 8mm videotape with a maximum storage capacity of 2.3 Gbyte. Data reduction does take place, but nevertheless one week of measurements at sea results in about 20 Mbyte of data. But then, with great accuracy, a measurement path of 100 meters at both sides of the "fish" at a time is achieved. Not only data accuracy but also data acquisition time is greatly improved by this new system. It is self-explanatory that not only a supertanker but also a Navy minehunter, that has the task to search for possible ground mines, is greatly helped by accurate depth charts, on which all obstructions are precisely recorded.

Electronic chart systems

Integrated navigation and one man bridge management are the main topics in modern navigation these days. The development around ECDIS (Electronic Chart Display and Information Systems) plays an important role in these concepts. Fully developed these systems integrate all navigational chart information with position and on demand other relevant information for safe navigation. The Netherlands Hydrographic Service (of our Navy) has been involved in the development of the electronic chart from the very beginning. Worldwide standardization of the systems is of vital importance. The first set of hydrographic specifications was drafted some 4 years ago under the chairmanship of the Netherlands Hydrographer. Nowadays the International Hydrographic Organization (IHO) and the International Maritime Organization (the IMO) work close together in finalizing a set of standards before the end of 1993. Close co-operation with the industry is essential to test the preliminary specifications. In the beginning of 1991 H.NL.M.S. Buyskes, one of our North Sea surveying vessels was equipped with a testbed system. The system was built by the Netherlands industry (Rietschoten & Houwens - Radio Holland) and the necessary chart data was supplied by the Hydrographic Service.
Furthermore the TNO’s Institute for Perception played an important role in these tests. In other countries, Norway, Germany and soon in the US, similar tests are organized. With the introduction of GPS for positioning, update possibilities of the system through IMO’s-INMARSAT, electronic chart systems have a great potential in improving the safety of navigation.

Every effort is made through the international organizations to speed up the process of coming to the final specs for ECDIS. Not surprising again it is also for our Navy of direct interest to acquire, by modern electronic means, precise topographical information. In combination with the precise seabed mapping, this will also enable us to locate unlawfully dumped material that can threaten our environment.

Training for safety

Damage by fire, flooding or otherwise is a threat to all ships at sea, and to naval ships in action in particular. But also in peacetime a small frigate with 200 man on board, various missiles and ammunition and propelled by aeroderived gasturbines at high speed and in close proximity of other ships, poses a challenge to safety.

Possible damage has to be controlled in order not to develop quickly into a disaster. This can be done by a well trained crew with modern means, if properly organised.

In general the quick reaction fire brigade on board consists of the engineering department personel. The size of this force can of course vary from submarine to frigate or minesweeper. But one thing they all have in common and that is that professional fire fighting and damage control training has been a basic feature of their naval education. The rest of the crew with lesser training in fire fighting and damage control, but all with basic skills in this, will assist if the calamity is bigger than can be handled by the engineers. Also the cook or the steward, the supply officer and the boatsvain know what to do. To train the whole crew as one team is one of the responsibilities of the captain.
But the man in actual charge is the Chief Engineer with his deputy. This is done in all warships from the machinery controlroom, from where all machinery, including the ventilation, can be operated. Not only remote control, but also comprehensive information and communication is available there. Damage control stations fore and aft in the ship are manned to take local control and action. Fire fighting equipment in use with us is not different from the merchant navy. Perhaps thermal imaging equipment to localise the source of fire in dense smoke, extensive use of air breathing equipment, also for all crew members as a personal safety and escape device, are less common on civilian ships.

But what is different is the sophisticated communication and data information exchange equipment on board of a warship. Good and quick information exchange and a subsequent ultra quick reaction lies at the heart of succesful damage control. At the moment we are experimenting on our newest M-class frigates the use of data exchange on VDU’s with keyboard and trackerball. Helmets with built in communication equipment are on trial as well.

The Falklands War was in fact the first time after World War 2 that any battle experience was obtained. The impact of missiles is a threat of this day and age. And it creates a great fire hazard in practice. And that creates on modern ships a tremendous smoke. The use of a closed circuit air conditioning and modern insulation materials and plastic furniture does not help! In that respect the dangers to all modern ships at sea are similar. In view of this experience the navy has separated the airconditioning in independent compartiments. Four to six air (and smoke) tight compartiments on a frigate. Also the amount of air breathing equipment has been increased. More in general, if fire prevention, fire containment and fire fighting are the three elements of fire control, a systematic approach has been chosen to make balanced improvements in all these three areas. Not only smoke containment, but also smoke prevention by careful trials and selection of cable and pipe insulation materials and bulkhead construction. Not only breathing equipment, but also quick reaction fire detection and extinguishing systems were tried and selected. Combined with a comprehensive sensor data display and checking system. Of course modern equipment to counter flooding or to remove water are part of the total damage control as well.
To practice and understand the proper use of equipment, thorough training of our crews is essential. For that purpose a specialised school in Den Helder is owned and run by my Navy.

As explained all crew members receive there the basic fire fighting and personal safety training for about one week. Advanced fire fighting training for the specialists in full sized representative ship compartments can be trained in real life conditions. Also repairing flooding damage can be exercised in a moving simulator built by the Rotterdam Drydock Company. Only a well trained team will be able to avoid becoming very wet indeed. Realistic environment simulation provides the real life stressors.

Team training in command and control of damage containment and repair is done on a different simulator. This trainer is a mock up of a frigate control centre where realistic scenario's can be computer simulated.

Nothing can simulate reality as well as a real ship. Part of the work-up of the crew is an extensive damage control training and exercise under the guidance of the training school. At a British work-up centre in Portland this is finished off in teams with other ships, submarines and aircraft. It seems a big effort. But as an insurance against uncontrolled fire and other shipboard damage it is never enough. A trained crew, a fire, smoke and damage resistant ship and modern fire fighting equipment are the key to safety at sea. Improvements in information display and communication are the most promising route to further enhancing safety in ships. Expert systems supporting the operators in the most efficient damage control are a promise for the future. But not a very distant future.

Safety in combat circumstances

A basic difference between a merchant ship and a naval vessel is that it might be exposed to the actions of enemy weapons.
It has to fulfil its mission under those circumstances and must be able to keep floating and if possible fighting when hit.

This is an extra design parameter which plays a decisive role in the total design process from forward design to detailed design. If a explosion takes place several destructive effects on the ship will result. When the explosion is in the air, outside or inside the ship, a blast wave will hit the structure. When the explosion is in the water the ship will be hit by a pressure wave which will propagate through the structure and cause fierce movements and extra loadings on equipment on board.

Another weapon effect is the impact of thousands of fragments. They can penetrate the structure with very high velocities.

During design all these effects have to be taken into account and since there is always a limitation of money, weight and volume, the solutions have to be balanced by a proper trade-off.

During the design-process computer models are made of the ship. Resistance properties against fragments and blast waves are included in this model. Additionally a functional model is made in which all equipment and their functional relations are included.

In this way an assessment can be made what the effect on the combat capability will be when a certain equipment is damaged.

Then the model is exposed to a threat environment like, for example, a fragment distribution.

As a result an assessment can be made of the combat capability remaining after such a hit. Possible improvements can be evaluated with this modelling technique.

Of course a ship can not be designed in such a way that it will survive all possible weapon effects. Therefore studies are made of the residual strength after a hit in order to be able to bring the ship and its crew back to the harbour. Models of the ship with assumed configurations will indicate where the weak points are.
These design tools are of great importance and a lot of effort is undertaken to validate and improve them. Research programs are underway to study damage mechanism related to these type of loadings to be sure that the algorithms in the codes are correct. This research includes tests in blast tunnels where a blast wave is simulated, shock machines where violent movements associated with an underwater explosion can be studied and detailed analysis by finite element calculations. That this is not simple might become clear when you realise that the explosion is a phenomenon in the microsecond range, the shock wave in the milliseconds and the response of the ship in the second range. This is a time span of ten to the power six. Whenever there is a possibility life tests are done in order to validate the models and see if they predict the damage correctly. Obviously we do not use our latest frigates for destructive tests. For that purpose a second world war frigate was sacrificed.

This is all done in order to try to improve the safety of ship and crew in wartime conditions which is one of the design requirements for a naval ship. Prevention of course is better.

Ultimate Stability Criteria

In coöperation with the navies of the Unites States, Canada, Australia and the United Kingdom the Royal Netherlands Navy sponsors a study into the improvement of stability criteria for frigates. The aim of this project is to develop rational criteria for ship capsizing. These intact stability criteria will be applicable for the design of frigates operating in moderate to heavy seas. The methodology involved may be applicable also to other hull forms. Whereas criteria in use today are typically based on transverse stability characteristics in calm water and beam excitation due to for example wind or turning, new criteria should reflect the influence of the environment in a more rational manner. Especially wave induced effects are to be included in a consistent way.
Theoretical research has progressed to the stage that numerical tools can be used with some confidence to obtain an indication of a ship’s behaviour in rough seas. Mathematical models, such as the time domain program FREDYN, will be used extensively to study the capsize behaviour of frigates in waves.

The MARIN study is structured such that

(a) The overall dynamic behaviour of a frigate is expressed in a complex mathematic model.
(b) Using this model a large number of simulation runs is performed with systematic variation of design, operational and environmental parameters.
(c) The effect of changes of each parameter on dynamic stability is assessed and the mechanisms responsible for capsizing are identified; the so called capsize modes.

Examples of capsize modes are:
* Broaching
* Loss of stability in following seas
* Wave excitation in beam seas

A complicating factor is that capsize modes do not always occur separately. Loss of stability in following seas can be followed by a broach.

Two parent hull forms were selected: A modern frigate hull form with wide aft sections and flare, and a traditional hull form, both designs with around 4000 tonnes displacement.

The next phase of the study will result in simplified relations between design, operational and environmental parameters in the one hand and the likelihood of capsize on the other hand.

These relations could then be used to obtain simple criteria for capsize. This study will also provide guidance for the ship designer. He will be able to assess the effect of changes in the design parameters on capsizing probability. The present criteria for naval ships will be thoroughly analysed in advance of proposing new criteria however.
safety margins in submarine design

In the structural design of a submarine or any other deep diving vessel the establishment of the safety margin against buckling collapse of the pressure hull is the main design effort.

The collapse load which can be carried by cylinders under external pressure is heavily influenced by the shape perfection of the cylinder. Small imperfections, e.g. deviations from the perfect circular shape, leads to a drastic reduction in collapse load.

In former submarine design procedures the pressure hull was dimensioned without taking into account the influence of the secondary structure on both the stresses and buckling behaviour. Secondary structures in this context are all structural parts which are not rotational symmetric, for example internal decks, penetrations and above all the outerhull as applied on the RNLN diesel electric submarines.

A common simplified design assumption in the past was to assume that all these kinds of secondary structure would not have a negative influence on the buckling load carrying capability of the cylinder. Or a positive one for that matter.

In the design of the deep diving new RNLN Walrus class submarine the use of high-strength steel enforced some new techniques, because it was found that this simplified procedure would not guarantee the required safety margins against buckling.

The secondary structure stiffens the pressure hull structure resulting in an increase in buckling strength. This beneficial effect is however only fully effective if the secondary structure does not collapse prematurely relative to the pressure hull.

However on the other hand, it also has a decreasing influence on the buckling strength since the secondary structure surrounding the pressure hull is not rotation-symmetric.

Because of this it impresses non circular deformations on the pressure hull. These non circular deformations combined with production out of roundness of the cylinder, decreases in turn the buckling strength of the pressure hull.
As part of the design of the Walrus class submarine, the RNLN started an elaborate program to establish the safety margins against buckling when the influence of the secondary structure is taken fully into account. This program consisted of three parts. Non-linear buckling calculations were performed in finite element (FEM) modules. Large FEM models were used, consisting of the pressure hull between two bulkheads and all the secondary structure. The non-linear relation between stresses and external pressure for the specific construction was established. Complementary to these FEM calculations extensive full scale strain-gauge measurements were performed on a segment of the submarine. These results were used to validate the stress distribution as calculated with the FEM models. Also buckling experiments on scale models of cylinders incorporations all kind of secondary structures and out of circularities were performed. These experiments were necessary because the accuracy of the computational schemes in calculating the buckling collapse load can only be verified with scale experiments, never with the real submarine!

The program resulted in much improved quantification of the safety margin against buckling collapse for submarines with complex constructional geometry like double skins. Based on this work and other ongoing research the RNLN is in the process of establishing an enhanced design procedure for submarine pressure hulls. Of course all these theoretical calculations had the happy final result that our Walrus class submarines have a depth capability unsurpassed in any conventional submarine in the world as proven safely in practice. And that is an essential feature of such a boat. The theoretical knowledge has however a wider application.

Summary and conclusions

Marine safety is translated in a very special way in the navy. Our environment, the sea, is however the same as that of our civilian brothers. Our advanced technology is universal and of the high standard expected of the Netherlands. It is that knowledge that makes us a respected and attractive international partner.
ut also nationally it should not be restricted to ourselves. It is therefore with pleasure that we participate in this symposium of the Delft Technical University, the breeding ground of most of our know-how. On our support you can count if your quality of the past 150 years is maintained.
What are the implications for education in marine technology?

J.B. Caldwell

It is argued that because of growing concern, reviewed in the first part of the paper, about maritime safety, responsibility for the assurance of safety will tend to move away from the regulatory agencies towards designers, builders and operators. Therefore, as discussed in Section 2, the marine technology professions must prepare themselves to accept such responsibilities, not least by appropriate changes to their programmes of education and training.

Part 3 of the paper reviews some of the problems of safety assurance, such as the identification and quantification of hazards, the influence of human factors, and the determination of acceptable levels of risk. This is followed by a brief discussion of design for safety where some areas of needed work are identified.

Based on the foregoing, in the final part 5 of the paper the Author's personal views on some needs and priorities in undergraduate education are given. Suggestions are made as to how safety considerations might become a more integral part of marine technology education, in order to prepare our graduates for their probable responsibilities in the 21st century.

1. INTRODUCTION : THE GROWING CONCERN FOR SAFETY AT SEA

Three months ago, at the end of February, 1992, there was published in London a Report entitled "Safety Aspects of Ship Design and Technology". This Report was prepared by the Select Committee on Science and Technology of the House of Lords (1992), who had been receiving and considering evidence during the preceding year from a wide variety of organizations, companies, research and educational establishments, as well as individuals concerned with various aspects of safety at sea. For its timing, content and recommendations, this Report is significant in the context of this Conference here in Delft. In the course of gathering evidence for their Report, members of the Select Committee visited only two Universities; and the fact that one of these was the Technical University of Delft testifies to the high regard in which this University is held internationally. It is thus a pleasure and an honour to be able to participate in this celebration of 150 years of service and achievement by one of the world's foremost centres for teaching and research in marine technology.

That a Select Committee of the House of Lords has devoted so much time and concern to ship safety underlines the growth of public concern following a series of highly-publicized marine disasters, too familiar to need to be listed here. There
can be little doubt that this increasing concern for the safety of life, property and the environment, and the associated pressures of litigation, will bring designers, operators and regulatory authorities under ever more critical scrutiny. It is essential that the maritime community - individuals as well as organizations - should respond in a professional way, and should be able to demonstrate that the assurance of safety at sea is based on the best available knowledge, techniques and procedures. Can we now honestly say that this is what we do? If not, what needs to be done? And what are the implications for the future education of marine architects and engineers? These are the principal questions which the Author will try to answer in this paper.

2. THE ENGINEER'S RESPONSIBILITIES FOR SAFETY ASSURANCE

In giving evidence to the Select Committee, the Author expressed the view that the marine professions suffer from a significant disadvantage: they are "over-regulated". Or, to put it more precisely, the many regulations to which, for example, ship designers must conform, are too detailed and prescriptive. Such regulations, whether concerning stability, subdivision, strength or almost any other aspect of design, prescribe that certain (generally empirical) criteria should be satisfied. The levels of safety (or risks of unsafety) thus obtained are seldom, if ever, explicit; nor is it easy to quantify how a proposed change in design would affect the real safety of the ship. In the absence of explicit links between design, regulations and safety, there has developed an understandable tendency in design to regard compliance with regulations as the main (almost the only) guarantor of safety. The general result has been to create a culture of "dependence on regulations" as a substitute for genuine "design for safety".

There will be many who argue, with some justification, that the availability of a wealth of detailed, prescriptive regulations has served the marine community well. They will point to the overall record on marine safety (Fig.1) showing a general downward trend in marine casualty rates. They will remind us that regulations which have evolved over a long period of trial and experience represent much accumulated wisdom; and by prescribing the resulting design requirements in detail, they save the designer a great deal of effort, time and cost.

Space does not permit a detailed discussion of the arguments for and against "design by regulation". But in the Author's view, as discussed more fully in Caldwell (1992), there will be a growing pressure for marine designers to take more explicit responsibility for safety assurance. Whether because of the difficulty in applying prescriptive regulations to novel designs, or because of the growing use of formal safety assessments in other branches of engineering, the need to move towards marine "design for safety", using modern ideas and techniques, must now be recognized. A similar view was expressed in the conclusions in the Select Committee Report (1992). Just a few months before the Committee began its work, there had been published the Report of the Committee of Inquiry into the disaster to the PIPER ALPHA oil platform in July 1988.
Although the findings of this important and influential report were specifically concerned with the safety of offshore structures, there is a widespread view that they have implications also for shipping and for the design, operation and management of ships. Thus the Cullen Report (1990), with its advocacy of formal safety assessments for offshore installations using the best available techniques of hazard analysis and risk assessment, indicates the way in which the assurance of safety at sea is likely to develop.

Of course any change from the present regime of safety assurance through the well-established system of regulatory authorities and prescriptive regulations towards the methods recommended by Cullen cannot, and indeed should not - take place overnight. We are already seeing, for example in the evolution of IMO regulations governing the subdivision and damage stability of ships, a recognition that rational rules must be based on a probabilistic approach to such hazards. Similarly the Classification Societies are increasingly using long-term statistical data in setting strength standards, and are carrying out various types of risk assessment for novel shipping ventures.

Such developments, however welcome and timely, are still largely centred in the regulatory agencies; whereas the view is clearly growing (e.g. in the references quoted above) that more of the onus for assuring safety should be borne by those directly responsible for the creation, operation and management of a ship - in short by the individual marine architects and engineers themselves. In the United

Figure 1 - Ship Casualties Show a Downward Trend

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Kingdom, the Engineering Council, which has an overall responsibility for the whole profession of engineering, has recently published for discussion an “Embryo Code of Practice” (1991) entitled “Engineers and Risk Issues”. This draft Code is intended to encourage engineers to recognize, and to prepare themselves to accept, a professional responsibility to ensure safety of life and of the environment. Thus the Code suggests that all engineers should, inter alia:

- recognize the need for a disciplined approach to risk issues and hence to human safety;
- continuously use their professional judgement and experience to ensure that risks are properly identified, assessed and controlled;
- be aware of the methods of risk assessment associated with their work and should regularly make necessary systematic studies to fully identify potential hazards.

Although Conferences such as this testify to the growing awareness in the marine community of our responsibilities in regard to safety, it must be doubted whether marine architects and engineers are yet properly equipped to deliver the kind of professional, numerate approach to safety assurance implied in the references noted above. This, then, is a challenge to our marine professions: to change our culture from over-dependence on regulations to acceptance of more individual responsibility for safety aspects of our work.

3. SOME PROBLEMS OF SAFETY ASSURANCE

To be able to accept such a challenge, and to take more direct responsibility for marine safety assurance in the artefacts we design, construct and operate, marine architects and engineers should be thoroughly familiar with the hazards of maritime operations, and should have the technical expertise to ensure that the risks of failure to withstand those hazards are likely to be acceptably small. Each of these elements of safety assurance - hazard identification, risk assessment, and design for acceptable safety - can pose severe problems; and it must be admitted that the education to which most marine architects are exposed probably does not yet equip them adequately to carry out these tasks.

We return later to the educational implications of preparing marine architects for the more safety-oriented responsibilities likely to face them in future. First, however, it may be helpful to review some of the particular problems of maritime safety, and the shortcomings (in the Author’s view) of our present systems of safety assurance.

It is not reasonable to expect that a formal safety assessment (FSA), of the kind which the Cullen Report (1991) proposed should be prepared for all offshore structures, would be required for each and every ship which goes to sea. But it is quite plausible to envisage a situation, perhaps five or ten years hence, when any new marine vehicle which embodies some significant innovation that might affect its safety, should be subject to FSA. It would be for the relevant national maritime authority, possibly guided by IMO, to decide what would constitute a “significant innovation”. This could refer to a novel concept of overall design (e.g. a “hybrid
lift" type of vessel), or the use of new combinations of materials, or propulsive systems; or it could result from a step-change in operational features, such as a reduction in manning or increased use of intelligent systems on board.

The task of “designing for safety” would then need to anticipate the main features of FSA, with the overall objective of assuring the certifying authority that the risks of incurring damage or loss during the prescribed life of the vessel, and in face of all the foreseeable hazards which it might encounter, would be acceptably small. The designers’ difficulties in doing this will be compounded by the need to work within tight financial constraints; - the cost of “designed-in” safety means that the definition of acceptable risk levels must be influenced by economic factors. Certainly designing for zero risk is not a practical option. We return to this point later.

Hazard Identification

The starting point of FSA is to identify the various hazards that the vessel must be designed to withstand. It might be thought that these are well-enough known from the accumulated international experience of seafaring; and in the general, qualitative sense this is true. But a quantitative safety assessment recognizes that the probability of loss of a ship is influenced both by the probability $P_1$ of encountering a hazard (such as an extreme wave) and the probability $P_2$ of not surviving that hazard (e.g. by capsize). Quantification of $P_1$ for a novel type of ship, perhaps with an ill-defined life and mission, and exposed to a variety of hazards from the environment (winds, waves, rocks, ice, other ships) or from within the ship (fire, explosion, cargo shift, human error), is a formidable task.

Historical, statistical data will be a major source of data for the quantification of $P_1$. This includes not only the growing bank of data on meteorological, environmental and hydrographic conditions in the oceans of the world; but also the many sets of casualty data relating to losses of ships or lives at sea. Presentations such as Figs. 2 and 3 are typical of the increasing volume of information which ascribes losses of ships and lives to certain categories of causes.

Such casualty data can be useful for making general deductions about maritime safety, for example in demonstrating general trends, or comparing performances under different flags, or showing the influence of ship age or operating area. But such data do suffer from some serious shortcomings, of which the following two are particularly relevant to the problems of quantifying marine hazards:

- the standard categories of causes of loss are too coarse and ill-defined, and it is difficult to deduce from them the real weaknesses or deficiencies (in design, construction, operation or management) which precipitated the loss;

- it is very rarely possible to ascribe a ship loss to a single event, as implied in the conventional casualty data. Almost always there is a sequence of events, each due to some mischance, malfunction or error, that eventually leads to the “top event” - the casualty itself.

Such deficiencies in the categorization of casualties are exemplified in Fig. 4, taken
Figure 2. The Broad Categories of Ship Casualties

Figure 3. Few Deaths Result from Casualties to Vessels
from Caldwell (1992), showing the interacting sequence of events which led to the disaster to the HERALD OF FREE ENTERPRISE. Statistics will record this as a ship that “foundered” or perhaps “capsized” (the distinction is not always clear). But the lessons learnt from this tragedy have as much to do with managerial and operational influences on safety, as with the actual design of ro-ro ferries. And such lessons can only result from a detailed unravelling of the full train of events preceding the top event, rather than by concentration on the final event as recorded in the casualty data. It follows that such data alone can be an unreliable pointer towards measures to assess hazards or improve safety.

Furthermore, it is evident that conventional sets of casualty statistics must be used with great care as a basis for assessing the risks of ships encountering various hazards. In the Author's view, a clearer insight into the hazards affecting marine safety would result not from the compilation of more “coarse” statistics of ship losses, but rather from more detailed studies of those accidents where the sequence of events can be reliably constructed, and weaknesses in the chain identified.

**Human Factors**

Herein lies another difficulty. It is well known, and confirmed by plentiful experience, that the weakest link the chain is often the human component. This predominance of human error in marine casualties underlines the crucial part which standards of training and competence play in ensuring the safe operation of ships. The setting of competence standards, and their enforcement, are primarily the responsibilities of national administrations and company managements; but the ship designer needs to be aware of what can reasonably be expected of competent operators. The growing use of smaller, perhaps multi-national, crews with more diverse qualifications and experience, underlines the importance of “design for operation”, for example through the ergonomic design and arrangement of equipment to maximize user-kindliness. Statistics of fatalities at sea (e.g. Fig.3) remind us that accidents or sickness on board account for a significant proportion of deaths. The designer can contribute to greater safety by seeking to eliminate any hazardous features in the design, construction and positioning of equipment. He will be greatly helped in this by having himself had experience of seafaring, perhaps as part of his education or training.

But perhaps the principal way in which the designer can explicitly make allowance for the much-maligned “human factor” in ship casualties is to recognize that it will never be eliminated, because people are imperfectible. Since accidents due to human fallibility will continue to happen, it must be a cardinal point of design to provide as much “damage tolerance” as is consistent with the efficient and economical operation of the ship. We need to explore further the implications and applications of this concept, though some useful ideas are now coming forward from recent research. In retrospect we can see that the principal design defect in the HERALD OF FREE ENTERPRISE was not that the ship was more likely to incur an accident (i.e. $P_1$ was acceptably small), but that it was unable to tolerate the consequences of a rare but credible accident, so that $P_2$ was unacceptably high.
Figure 4. The Herald Disaster Typified the Multiple Events Which Cause Ship Casualties
in relation to this particular hazard (crew negligence in not closing bow doors).

Acceptable levels of risk

Even if both components, $P_1$ and $P_2$, which determine the overall risk of damage or loss due to each significant hazard can be estimated, there remains the problem of defining what (non-zero) level of risk can be tolerated. The growing use of a probabilistic approach to safety only ultimately makes sense if safety levels and standards are then defined by reference to maximum permissible risks. This question is already being faced in other sectors of engineering (e.g. chemical, aeronautical, nuclear) and tolerable risk levels defined. In marine work, apart from some interesting and valuable recent studies of some specific marine hazards, the development of a probability-based approach to overall ship design is evident in the evolution of new IMO regulations governing subdivision and damage stability. Even here, however, such concepts as the Required or Attained Index of Subdivision have a largely comparative value, and cannot yet be related to the actual risks implicit in the observance of such rules.

This is not to criticise this welcome development, but rather to emphasize that much remains to be done to bring marine risk evaluation to the stage achieved in some other areas of design and operation. Assuming, as argued earlier, that marine safety will be expected to move in this direction, it is therefore not too early to begin to address the problem of setting acceptable risk levels for marine vehicles and operations. The matter is discussed more fully by Caldwell (1992, 1983); here there is space only to note one difficulty and a possible way ahead.

Specification of permissible levels of risk will probably be based on two approaches: the use of historical data to deduce risk levels apparently incurred in seagoing operations; and comparisons with other occupations and activities to derive risk levels which appear to tolerable or unacceptable to society. A formidable literature already exists in this field, and risk specialists make much play with notions such as “perceived” versus “actual” risks, and “voluntary” versus “involuntary” risks; all of which must influence the setting of risk standards. But for the maritime community there is an added complication resulting from the international nature of many seafaring activities. As Spouge (1990) has demonstrated in relation to ferry operations in the Philippines, the risks which society appears willing to tolerate (or can afford to reduce) vary greatly among maritime nations. The risk of death of a passenger on a Philippine ferry has been estimated by Spouge to be about 150 times as great as for a passenger on a U.K. ferry; but the HERALD tragedy, resulting in 193 deaths, seems to have stimulated much greater change in U.K. ferry design and operation than that following the loss of the DONA PAZ in which about 4400 passengers died.

Here is an aspect of marine safety which IMO may need to address on behalf of the global maritime community. Such disasters remind us also of the need to ensure that levels of permissible risk should somehow relate to the seriousness - in terms of the number of lives which might be lost, value of property at risk, or potential damage to the environment - of failure to withstand any hazard. The Author has
long favoured the development of risk standards derived from curves relating the
frequency of accidents F to the seriousness N of their consequences - now referred
to as F-N curves.

Fig. 5, based on information provided by Lloyd's Register of Shipping, illustrates
how such F-N curves might be used to define permissible levels of risk. The
curves were derived from historical accident data for various types of ship. Clearly
both the general slopes of such curves and their relative positions are important
indicators of relative safety. The use of an "iso-risk" line (such as FN = 10 in
Fig. 5) to define risk limits in relation to potential consequences seems well worthy
of further research and development.

Figure 5 - Frequency - Consequence Diagrams May Provide
A Basis for Defining Acceptable Levels of Risk

4. DESIGN FOR SAFETY

If ship designers in the 21st century will be expected - perhaps required - to provide
explicit evaluations of the safety of proposed designs, there must be available
suitable methods and analyses to underpin design for safety. Such a methodology
is not yet available; and in the Author's view, its creation should now be given
high priority in the funding of R & D.
Some of the essential ingredients in design for safety have emerged in the discussion above. They include the capabilities to:

(a) identify and quantify all significant hazards;
(b) evaluate the risk of damage, loss or death if any hazard is encountered;
(c) define limiting levels of acceptable risks of such events;
(d) develop designs (and operational procedures) which comply with such levels.

(a) and (c) have been discussed above. For (b), there is now available (at least in principle) a variety of techniques for risk assessment, some of which are beginning to be applied in marine work. Other papers presented to this conference illustrate ways in which formal safety assessment techniques, including reliability analysis, probabilistic evaluations, failure mode and effect analysis, fault tree analysis and others can be brought to bear on design, engineering and operational aspects of ship safety. Some of these techniques are rather new to marine technologists, and few have yet been included in most undergraduate educational programmes. Some of them also make considerable demands on computing capabilities and facilities, but this becomes less of a problem as such capabilities increase.

In the Author's view, the main aspect of item (b) above in which more R & D is required is in the modelling of unsafety. In much of the scientific and mathematical work which provides the foundation for education in marine technology and for ship design, the main emphasis has been on the classical "linear" response of engineering systems to external stimuli, such as changes in their environment. In many cases, the system behaviour is also treated as quasi-static. Much of the traditional teaching concerning marine structures and stability, for example, is presented in these rather idealized, albeit analytically elegant and tractable, forms. But, in safety matters, the reality is often very different. The behaviour of a ship, as it nears a limiting state at which it (or its occupants) become casualties, may well be highly non-linear, dynamic and possibly influenced by events (such as progressive or cyclic flooding) which are neglected in conventional assessments - and in conventional regulations - concerned with safety assurance. For how much longer can we justify the fiction of believing that the static GZ curve is a proper criterion to judge the safety of a damaged vessel undergoing extreme interacting motions in severe confused seas?

Thus the challenge to the ship science community now is to develop more reliable models of extreme responses of vessels, structures, systems and equipment, from which their limiting capabilities can more accurately be assessed. This would be a major contribution to marine safety. Even if, as an interim stage before requiring formal safety assessments of ships, we move from the present dependence on satisfying prescriptive regulations towards the use of performance criteria as the principal tool in safety assurance, the assessment of performance and the limits of that performance will still require greatly improved methods of modelling system responses to extreme conditions.

The final item (d) noted above calls for the creation of efficient synthesis procedures of design for safety. The main need is that safety considerations should
increasingly permeate the design process, and influence design decisions, from its earliest stages. Hitherto the ship designer’s main concerns have been to ensure efficiency and economy in his product. Safety has generally been handled by post-design checks to ensure that the relevant prescriptive regulations have been satisfied. It is well known that decisions made at the concept design stage can have a profound effect on efficiency and economy. So also do they influence safety; so procedures are needed for assessing the effects of alternative design options on safety. Such procedures need to be of increasing sophistication as the design proceeds, culminating in FSA as the final check on the developed design.

Some indication of the way in which Intelligent Knowledge Based Systems can be developed to provide the core of such a design process has recently been presented by Sen and Gerigk (1992). Although this is concerned primarily with safety against foundering following flooding damage, the methodology appears capable of extension to design against other hazards. The same research group is now working on a more ambitious research project entitled “Design for Safety”, one of eight major projects in a programme for which the Engineering Design Centre at Newcastle University has been awarded grants exceeding one million pounds. The overall intention of this project, as its name implies, is to create a practical and versatile methodology whereby the design of large made-to-order artefacts, such as ships and offshore structures, can incorporate safety considerations ab initio, working within the constraints of whatever safety regulations or regime are in force.

In the early development of such procedures of design for safety the emphasis will no doubt be primarily on generating designs which combine optimal efficiency (in the functional sense) with adequate safety (as prescribed by regulatory authorities). There remains the question, touched on earlier, whether there also exists an optimal level of safety. This in turn raises the question of the cost of safety, a delicate matter on which much work remains to be done. A strong case for a more sustained and scientific approach to the study of the costs and benefits of safety was made by Goss (1989) and re-stated in his evidence to the Select Committee on Science and Technology (1992). But we are still some way from having available agreed methods for putting a value on loss of life, damage to the environment, or on the public perception of safety.

For the immediate future then, the designer can probably do little more than attempt to include cost in design for safety by reference to the effects of design changes on capital costs, and possibly on revenue, repair and insurance costs. Again there may be value in studying developments in other sectors of engineering (e.g. aeronautical, offshore) where some interesting efforts are being made to determine optimal levels of safety. This involves examining the trade-offs between risks of failure and the resulting life cycle costs and benefits. Of course any “optimal” level of safety thus obtained must be not less than the prescribed level. Which brings us again to the basic requirement that acceptable and actual safety levels must be made much more explicit than is presently the case.

Clearly design for safety has a long way to go and much is to be done. Not least, our
future designers need the skills and attitudes to equip them to take responsibility to ensure the safety of our seafarers and marine community in the coming years. They should be educated accordingly.

5. EDUCATION FOR SAFETY

Should we, therefore, make any significant changes in the way we educate and train marine technologists to face their future responsibilities? This paper has attempted to sketch the kind of safety scenario in which future naval architects and marine engineers might have to work, and has touched on some of the professional and technical problems which may need to be faced, especially if designers are required to accept more explicit responsibilities for safety assurance. How then, if at all, might their “formation” as engineers of the 21st century, need to change?

Although engineers at all levels have a contribution to make to the assurance of safety, it seems appropriate, since this Conference is to celebrate the achievements of a distinguished University, to limit this discussion to the education of professional, graduate (in U.K., chartered) engineers. Again, in the light of Delft’s notable contributions to the education of marine technologists, the Author (because of his own experience also) will address particularly the education of naval architects and marine engineers.

Educators and curriculum designers these days are caught in a dilemma. On the one hand, the relentless expansion of knowledge, and the recognition that professional engineering often requires managerial, financial and communication skills as much as engineering science, has led to enormous pressures not only to “broaden” courses, but also to include new analytical topics or aspects of the subject. On the other hand, Universities in most countries now are under pressure to be more “productive”, to increase output, to reduce unit costs, to spend more time fund-raising, to interact with industry and commerce, etc., etc. In U.K. Universities, the triple pressures of expansion, accountability and commercialization have transformed (for the worse?) the environment in which academics can find time properly to define and deliver a higher education appropriate to the needs of future graduates. Pressures to equip graduates with particular skills of current value to employers must be moderated by the recognition that such skills can now more rapidly become obsolete. Likewise pressures to produce various kinds of specialist graduate, even within our particular sector of marine technology, may ultimately disadvantage the graduates themselves, who surely need a broader base of engineering education to face an uncertain future. Moreover, any segregation into specialist streams or “tubes” of study can lessen the healthy and informative influences of developments in other sectors of engineering. This is especially true of safety engineering.

So the Author has come to the view that Universities should seek to redefine the overall philosophy and objectives of their educational programmes, and perhaps return to some of the original ideas which informed undergraduate education. These might, for example, lead to curricula which:

- develop the ability to think creatively rather than to perform specific routines
- emphasize, and build on, the unity of engineering, rather than encourage its continuing fragmentation
- give priority to knowledge and skills which are enduring, adaptable and versatile
- provide more time to "learn by doing"
- encourage the art and science of synthesis alongside those of analysis.

Against such general desiderata for undergraduate education, how then might "education for safety" be stimulated and introduced? In the light of the foregoing opinions, the Author would reject the idea that safety engineering should now be "bolted on" to our already overcrowded curricula in marine technology. This is not to deny that, probably at postgraduate level or as part of Continuing Professional Development (CPD) there could be value in specialized intensive courses concerned with the techniques and applications of safety engineering. Such courses should preferably cover many disciplines of engineering to ensure cross-fertilization of ideas and techniques.

The main need at undergraduate level is to develop in the engineering student a consciousness (as well as a conscience) that safety is an important part of his professional responsibility; that safety engineering is an indispensable part of design; that technical methods of safety assurance are becoming available, but that safety assurance has human, operational and managerial, as well as technical, dimensions. The main influence which marine architects exercise over safety is through design; so it follows that the main thrust of education for safety should be through the teaching, and practising, of design. There is (at least in U.K.) much current debate about - and criticism of - the teaching of design in Universities; and there is no general agreement yet as to what constitutes a good course in design. But if design is to be presented as the process of decision-making under constraints and uncertainties in order to define the artefact with the "best" set of attributes for its intended function, then what is being suggested here is that those attributes must explicitly include safety.

Undergraduate education, however, should do much more than just pay lip-service to the importance of safety through general exhortations and qualitative statements. The naval architect of the future needs to be able to assure safety; he needs a rationale, methods, equipment. But if there is no room to add to his course specialized studies of reliability analysis, FMEA, and the like, (which might be the subject of postgraduate study or CPD), what can be done to prepare the ground, to sow the seeds of safety engineering, and to cultivate the right approach to safety during his undergraduate studies?

The brief survey of the problems of safety and design for safety, given earlier in this paper, suggests a number of ways in which undergraduate courses might change some priorities and emphases in order to encourage a more safety-conscious formation in marine technology:-

(a) In introductory courses concerning ships and the sea, as much attention _should be paid to failures as to successes_. Not only does failure promote more
progress than success; a study of casualties can show students the variety and nature of the many hazards against which ships must be designed.

(b) *Statistics and probability* are of such fundamental importance to safety engineering (and to many other aspects of marine technology) that this branch of applied mathematics should permeate the entire undergraduate course. Study of the sea and ships and casualties provides a rich source of examples and applications of statistical and probabilistic concepts which give reality to what is often (to the student) a rather dry and formal area of science.

(c) Likewise the concepts of *uncertainty, risk, reliability and safety* can be introduced and exposed in many topics within marine technology. Emphasis on certainties and single-solution problems must be replaced by a healthy realization that the real world is uncertain, open-ended, capable of many possible solutions.

(d) Work in engineering science should give greater prominence, as suggested earlier, to the *prediction of the way things fail* under extreme conditions as much as to "linear", day-to-day behaviour under normal operating conditions.

(e) The *ability to model the "real" world*, - imperfect, dynamic, irregular, - rather than an "idealized" world should constantly be borne in mind in developing the analytical capabilities of students.

(f) The idea that safety is basically assured by designing so that the *capability* of a system or structure to withstand changes in its environment exceeds the *demand* made upon it, should be seen as fundamental. The fact that both demand and capability are probabilistic, and often time-dependent, reinforces the importance of (b) and (c) above.

(g) Although students must be made aware of the regulatory system, and the principal regulations, within which the designer must currently work, it is suggested that *less time should be spent on detailed study of current regulations*. The emphasis in design for safety should move from the satisfaction of empirical, prescriptive rules, towards the assurance that certain explicit standards of performance will be achieved.

(h) The concept of *damage tolerance* through fail-safe design should be developed and encouraged in lectures and course work in design. In systems design, especially, the value of redundancy or alternative load paths should be emphasized and demonstrated.

(i) In the teaching of management subjects, the *responsibilities of management* as well as individuals, in relation to safety should be explained and emphasized. Factors influencing human response to emergency include not only individual competence and training, but also the operational system and managerial culture within which work is carried out.

(j) The development of *design for operation* through the increasing use of techniques such as ergonomics, simulation, IKBS etc. can do much to improve safety, not least through the reduction of accidents on board and the effects of human error.
The value of *sea-going experience for students* cannot be overemphasized. Here is an aspect of education for safety to which shipping companies can make a most crucial contribution by affording opportunities for undergraduates to learn from living, and perhaps working, on board ships during vacations or soon after graduation.

A final general point. Teachers, as well as students, of marine technology must avoid living in "watertight compartments". So much of recent advances in safety assurance have come from other branches of engineering that it is essential for us to learn and adapt ideas and techniques from other disciplines, and to distil the best of these into our courses and curricula.

Let us hope that, in such ways, when TU Delft next has cause to celebrate an anniversary, it can look back with pride on real and demonstrable progress towards ensuring greater safety for those who work and travel on the waterways of the world. We will all wish the University well in its future endeavours.

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2.2 Ship handling in Ports
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The objectives of the Rotterdam Municipal Port Management

The main objective of the Rotterdam Municipal Port Management (R.M.P.M.) is to promote activities in the port and industry of Rotterdam.

In order to achieve this the R.M.P.M. has three key functions:
- management of port infrastructure
- provider of nautical services
- co-designer of port innovations.

In the organisation of the R.M.P.M. for each key function a directorate is responsible.

The Directorate Shipping is responsible for the second key function: providing nautical services.

The main objective of the Directorate Shipping is: Supporting the economical process by realisation of an efficient navigation in the port, under the conditions of a sufficient safety level and limited environmental effects.

This objective is strived after by operating an optimalized nautical infrastructure and by means of an effective information process.
THE ROLE OF SAFETY

Introduction

Following our main device it is clear that safety is no goal in itself but has to be evaluated together with other interests. This implies that a certain degree of risk has to be accepted. The key question is: which level of risk is acceptable.

The appropriate framework for answering this question should be found in a safety policy.

Safety can be seen as divided into four aspects:
1. Safety of the shipping traffic
2. Safety in the transport of dangerous goods
3. Safety of the (marine) environment
4. Occupational safety.

As the R.M.P.M. has no authority in the last type of safety - this is the working field of the Labour Inspectorate - just the first three items will be explored further.

General objectives of a safety policy

In accordance with the overall objective of the Rotterdam Municipal Port Management of promoting activity in the port and in the industry, three safety objectives are defined:

- to maintain a sufficient level of safety inside the port. This objective is aimed at the internal safety of the port and its industrial area. The intent of this objective is to ensure that all activities can take place unhindered by accidents, their effects or risks to public health;

- to maintain an acceptable level of risk to the public outside the port and industrial area. It is the responsibility of the authorities to protect the quality of life in the region from the hazards inherent to port activities. These activities must be conducted in such a way that all reasonable precautions are taken to protect the safety and health of the public as well as the quality of the environment outside the port;
- to maintain such a water quality in the port that
  the sludge can dredged out of the harbour basins
  without any restrictions.
  If the water in the port is polluted due to ship­
  ping or industrial activities extra (costly) pre­
  cautions have to be taken in order to handle the
  dredged materials.
  Polluted water and/or sludge threaten the long­
  term survival of the port. It is the responsibili­
  ty of the authorities to ensure that (industrial)
  activities still will be possible in the future.

The safety in shipping traffic can be seen as the
  internal safety of the system, the transport of
dangerous goods is determining the external safety.
Protection of the environment means safety for the
  system in the long-term.

This paper we will further concentrate on the second
type of safety. Especially the transport of dangerous
goods is relevant in this respect.

TRANSPORT OF DANGEROUS GOODS

Seagoing

Approximately 45% of the total cargo in tonnes hand­
led in the port of Rotterdam is classified as dange­
rours. 98% of this dangerous cargo consists of liquid
bulk, of which crude oil is the main component.
Around 51% of the number of ships entering the port
carry dangerous goods.
In 64% this implies the transport as packaged goods,
like boxcontainers, tankcontainers, drums etc. Almost
95% of the notifications to the port authorities
relates to this mode of transport.

For packaged goods and liquid bulk as well holds that
the majority of the notifications deals with relati­
vely small quantities. This also implies that a wide
variety of chemicals is involved.

The transport of dangerous goods is concentrated in
the Maasvlakte/Europoort area (84%) and into a smal­
ler extent in the Botlek area (12%). At the Maasvlak­
te/Europoort this means in most cases crude oil,
whereas in the Botlek a wide variety of chemical
products is handled.
In the Waalhaven/Eemhaven/city area predominately packaged dangerous goods, containers included, are handled.

Approximately 60% of the packaged dangerous goods are transported in boxcontainers.

Around 40% of the in Rotterdam unloaded dangerous goods are carried by pipeline, around 25% by inland barge.

Table, Dangerous goods notifications in 1990

<table>
<thead>
<tr>
<th>Type</th>
<th>Number</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seagoing (according IMO)</td>
<td></td>
<td>no. of ships</td>
</tr>
<tr>
<td>Gastanker</td>
<td>404</td>
<td>1.3</td>
</tr>
<tr>
<td>Crude tanker</td>
<td>746</td>
<td>2.3</td>
</tr>
<tr>
<td>Parcel tanker</td>
<td>3,995</td>
<td>12.4</td>
</tr>
<tr>
<td>Combination carrier</td>
<td>169</td>
<td>0.5</td>
</tr>
<tr>
<td>Total Tankers</td>
<td>5,314</td>
<td>16.5</td>
</tr>
<tr>
<td>General cargo (incl. containers)</td>
<td>11,201</td>
<td>34.8</td>
</tr>
<tr>
<td>Total</td>
<td>16,515</td>
<td>51.4</td>
</tr>
</tbody>
</table>

Inland Barges (according ADNR)

<table>
<thead>
<tr>
<th>Type</th>
<th>Number</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tankers</td>
<td>1,729</td>
<td>-</td>
</tr>
<tr>
<td>General cargo (incl. containers)</td>
<td>1,681</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>3,410</td>
<td>-</td>
</tr>
</tbody>
</table>

Inland barges

Per year approximately 23 million tonnes of dangerous goods are transported from Rotterdam by barge and around 7 million tonnes to Rotterdam. There are per year around 25,000 ship movements with dangerous goods to Rotterdam.

In the port of Rotterdam 40% of the ship movements of inland barges are related to the Botlek area and 30% to 1st and 2nd Petroleumharbour.
Safety policy

From the general objectives two main objectives for dangerous goods can be derived:
1. Prevention of accidents in the port
2. limitation of the effects should accidents occur.

For further specification accidents are categorized:
- 'daily' incidents, characterized by a high frequency (> 10^-4 yr^-1) and small effects (≤ 100m)
- large scale accidents, characterized by a low frequency (≤ 10^-4, ≥ 10^-6 yr^-1) and major effects (> 100 m, ≤ 500 m)
- catastrophes, characterized by a low frequency (<10^-6 Yr^-1) and enormous effects (> 100 m, ≤ 500 m)

These accident categories have their own prime instrument in the overall policy.
- catastrophes ---> prevention
- 'daily' incidents ---> physical planning (i.e. zoning as instrument of separating port activities and built-up areas)
- especially for the accidents with major effects the incident fighting organisation and equipment is scaled.

Risk

It will be obvious that the word "dangerous" only refers to situations where substances have escaped their containment. Thus, risk is related to accidents in which dangerous goods escape from their containment. Risk is considered as being a function of the effect of an accident and the probability of this accident to happen.

Especially the transport of dangerous goods forms a risk to the public outside the port area. In special transport risk analyses this public risk is calculated and assessed according to standards that are derived from standards for the (process)industry.

This method of assessing risk is applicable for general decisions on the acceptability of the transport of dangerous goods.
An example: the transport of packaged dangerous goods

Introduction

Studies have shown that the probability of an accident with packaged dangerous goods during the transport cycle is highest at the moment of loading or unloading. The probability that, for example, a tankcontainer aboard a ship is damaged such that the contents start to flow out as result of a collision during sailing in the port is practically neglectable.

Further, at the moment of transshipment the cargo is lifted over a great height (12 to 15 meters), so a fall might seriously damage the packing.

Due to the nature of (modern) general cargo the types of packagings vary widely. However, dangerous substances can be divided into two categories: those able to cause effect restricted to the transport area and those capable of causing effects over a larger distance.

Looking especially at the latter category - excluding explosives and radio-active material - it concerns the gasses, either pressurized or liquified, and volatile liquids. These substances are - in general - transported in cylinders, tankcontainers and metal drums.

Probability

Looking at probability first, a number of factors are of influence:
- type of packaging
- procedures
- actual method of handling.

Some frequencies of critical damage to several types of packagings resulting in loss of dangerous substances are presented in table ...

Typically the accidents with drums can be considered as daily incidents. And in a lot of accidents with drums the complete contents are lost.

The reported accidents for tankcontainers referred only to leaking valves. So, no accidents where the complete contents of a tankcontainer were lost have been reported.
This point has given reasons to do some further investigations upon the damaging of tankcontainers as a result of a fall from great height. Several dropping test were performed by the Bundesanstalt für material prüfung at a test site near Braunschweig. In this test series a light type of gastankcontainer was dropped from a height of 12 meters, filled with water and pressurized up to 9 bars, onto a flat, rigid concrete platform.

This experiment did learn us that the maximum credible accident where tankcontainers are involved is a hole punched into it due to hitting an obstacle. This causes an outflow during maximally one hour till the moment that the contents are lost completely. But, undoubtely transporting dangerous goods in tankcontainers is a very safe way of transport.

Looking at the types of packagings for dangerous goods, it means that the typical incident will comprise the release of the contents of a drum (250 l.) or tankcontainer (max. 28 m3) with a liquid or the escape of a gas from a cylinder (50, 150 or 1.000 l.) or tankcontainer (max. 20 m3).

For the most of the volatile liquids the distances over which dangerous concentrations could occur, will be restricted to ca. 100 m. and for most gases to ca. 500 m. Only for a few substances - mainly gases - the effects can reach farther.

Concerning BLEVE’s, dangerous distances in the order of 500 m. occur for a tankcontainer with e.g. propane. Contrary to poisonous substances, flammable substances can cause chain-reactions. So, for storage, maximum amounts of flammable substances have been decided upon as well as suitable segregation distances from each other and from poisonous substances.

When it comes to the possibilities of reducing the effect of incidents there are structural methods and curative methods.

One of the structural methods is the use of planology to separate activities with dangerous goods from residential areas.
And, finally, there are curative methods to limit the effects of an accident. Accident fighting is primarily the responsibility of the partners involved: ship and terminal. When the magnitude of the accident is beyond their capacity the authorities should step in.

So it is unavoidable to prepare emergency plans, make proper materials and equipment available and ensure that personnel is well trained.

A key factor is the speed at which dangerous substances can be identified in case of accidents.

A computer databank like Rotterdam’s SISTER is a powerful tool in making these data readily available.

The proper application of and adherence to legal regulations have a reducing influence on the probability of accidents.

In addition to legal requirements ship owners, stevedores etc. set up their own procedures. These may aimed at higher efficiency but they usually lead to greater safety by consequently reducing accidents probability.

As a third factor the actual manner in which dangerous goods are handled is of substantial influence on the probability of accidents to occur.

It will be clear that the use of proper equipment, by trained people, strongly reduces the probability of accidents.

The effect

The second major factors is the effect of an accident. This effect may be influenced by a number of factors, such as
- Properties of the released substances
- The quantity released
- Possibilities to reduce the effect
- Planology.

Dangerous substances vary widely in their properties. They can be toxic, flammable, corrosive etc. It is clear that the effect is very much dependent upon these properties. Other conditions, in addition to the product’s properties should also be taken into account: wind speed and
direction, temperature and atmospheric conditions determine evaporation and dispersion and hence the area which is endangered.

It goes without saying that the effects of an accident with a dangerous substance is proportional to the released amount.

SISTER stands for Substances Information for Ship Transport and Emergency Response and is a registered trademark of the R.M.P.M.

The system contains 4 functional modules:
- Substance Identification and Properties;
- Bulk Transport Legislation;
- IMDG-code Transport Legislation;
- Accident Information.

SISTER is not only designed for use during accidents. It is in the first place capable of providing ample information to the R.M.P.M.’s dangerous goods inspectors for their day-to-day job.

The zoning system for handling packaged dangerous goods

An example of following a policy where by means of planology possibly dangerous activities are separated from people living near the port is the zoning system for handling packaged dangerous goods.

As the frequency of accidents with packaged dangerous goods is relatively high it was the intention of the policy makers to make use of separating port activities and built-up areas in order to guarantee the safety of people living close to those activities.

For all substances out of IMDG-code classes 2, 3, 6.1 and 8 calculations were made. With hypothetical accidents scenarios for the relevant, allowed packings distances were found over which deadly concentrations could occur.

Using a zoning system based on distances available between berthing location and living quarters, for each zone the allowable maximum size of packagings and total quantities for groups of dangerous goods are given in tables in the Port Bye-laws. Activities are permitted at such locations that in case of an accident the distance to living quarters exceeds the calculated effect distance.
In the A (0-100 meters), B (100-300 meters) and C (300-500 meters) zones there are restrictions in maximum size and quantities as well. In the D (500-1,500 meters) zone all sizes are allowed but for some groups maximum quantities are given. And finally where the distance is more than 1,500 meters there are no restrictions at all.

It is the intention of the policy of the Rotterdam Port Management to make rules that give forwarders at forehand insight into possibilities of handling dangerous goods in the Port of Rotterdam. So they can plan ahead and have no delay when a ship arrives in Rotterdam.

Need for information

On of the major conditions to be met in order to guarantee a good safety level via prevention is undoubtedly the availability of reliable and up-to-date information upon the number, location and type of activities in the port.

By means of notification form, which is specified according to Dutch national legislation, the transport of dangerous goods by seagoing ship has to be declared at the competent local authority - in Rotterdam this means at the Harbour Coordination Center.

On this paper form the most important items are: name of the ship, berth, estimated time of arrival, correct technical name of the dangerous substance, the UN-number, quantity, activity (loading/unloading/transit), IMDG-class and flashpoint, and stowage location.

For practical reasons this form has two variants, one for liquid bulk and one for packaged goods and dry bulk.

Experience has shown that one of the problem is to have the right combination of UN-number and correct technical name. It is insufficient to use a trade name or just the proper shipping name.

The use of improper nomenclature is a well-known source of confusion when it comes to applying the proper rules or in case of incidents.
It was exactly this problem that made the R.P.M. decide to set up a database containing the necessary information: SISTER.

A study was set-up to see what the possibilities are to improve this notification process between the ship’s agent and the Port Authority. The study showed two points capable of improvement: the format of the notification and the quality of the contents of the declaration. Another possibility to improvement would be the use of telematics.

Conclusion

In view of the Rotterdam Municipal Port Management the real added value of an electronic notification would lie in a construction where the receiver (RPM) and sender of the Dangerous Goods Declaration could both use the same reference tables, i.e. SISTER, to fill in and check the combination of names, UN-number and IMDG-class.

In such a situation the advantages are:
- Uniformity in nomenclature
- Clear interpretation of legislation
- No unnecessary delay in incident fighting.
Safety and environmental protection in the port and industrial zone of
the port of Le Havre

G. Velter

This exposé provides a general overview of the Port of Le Havre and its Port Industrial
Zone.

The port's geographical situation and economic role are described.

Safety and environmental protection in the Port Industrial Zone is analyzed through the
examination of the following:

- facilities and accommodations offered in the port for ship reception, especially for the
  transit of dangerous goods,

- conditions for the organisation of safety and pollution control through a look at the
general applicable regulations and emergency pollution control and accident plans.

- the port establishment's policy concerning port and industrial development and
  environmental protection.

Subjects dealt with range from industrial risk prevention through the application of the
SEVESO guidelines to the problems of protecting sensitive natural environments.

The conclusion defines the stakes present which are the results of the rapid development
of port and industrial technologies and the growing sensitivity on the part of populations
and public authorities concerning safety and environmental problems.

I - General Overview

The word "havre" means shelter in French.

As indicated by its name, Le Havre was a port before it became a port city.

King Francis I founded Le Havre in 1517.

The port, which, like the city, was almost completely destroyed in 1944, has been entirely
reconstructed and widely developed.

Thus, Le Havre, the port and the city, have become a modern unit.

Situated at the immediate outlet of the Paris Region, the Port of Le Havre has an
exceptional position in the center of the North European seacoast which allows it to offer
excellent passage conditions for transoceanic trades which sail down the English Channel
- it is the first port to be touched on import and the last on export. Its position allows it to
guarantee the shortest service for all European countries (Spain - Italy - Northwest Europe).
Le Havre is first among French ports in terms of external trade. It ensures:

-55% of container traffic for all French ports

-and 40% of oil supplies.

In all, 58 million tons of goods, 8,000 ships and 1 million passengers transited in the Port of Le Havre in 1991. In addition, the port is backed up by a vast industrial zone set up by the Port of Le Havre Authority which covers almost 8,000 hectares and offers sites suitable for all types of industrial activity.

It is a deep-sea port, directly accessible to ships from the high seas 24 hours a day.

The François Ier Lock, which serves the Industrial Zone, is accessible to 250,000-ton ships.

Thanks to investments and a competitiveness plan put into effect by the Le Havre Port Community, the Port of Le Havre has, for several years, shown one of the best rates of traffic growth of all large European ports.

It is presently in fifth place among large European ports in terms of overall traffic and holds 10% of the general cargo market for all of Northwest Europe.

II - Accommodations Available to Ships

II.1 - Facilities

Energy trades make up 70% of port activity in tonnage.

Goods which might possibly present a risk to the environment, in varying degrees, make up more than three quarters of all goods transitting through the port.

Given the nature of products transiting in a large port, safety and environmental protection must be considered with the upmost seriousness.

The design of port facilities and equipment as well as the drawing up of relevant safety rules condition to a large degree the success of procedures in this area.

II.1.1 - The Reception and Expedition of Hydrocarbons and Chemical Products

At the entrance to the port, separate from other port facilities and approximately one kilometer away from the first inhabited areas, the Port of Le Havre has set up and dedicated a first oil facility, the oldest, allowing for the reception of ships up to 300,000 tons.

The facility, operated by the CIM (Compagnie Industrielle Maritime - Industrial Maritime Company) has 9 specialized berths and storage tanks with a total capacity of more than 5,000,000 square meters for crude oil and oil by-products.
In addition, the Port of Le Havre has constructed an oil terminal at Antifer, located 20 km to the north of Le Havre, which can receive the largest oil tankers (550,000 tons).

This terminal has particularly favourable access conditions as well as two berths in the shelter of a very imposing breakwater measuring more than three kilometers.

A storage yard located at the foot of the cliffs holds 4 150,000 square-meter tanks which make it possible for the discharge and reloading of cargoes for Le Havre to take place in good commercial and safety conditions.

There are many facilities set up in the Port of Le Havre Industrial Zone. These are either specialized public facilities or private facilities directly serving production units in the industrial zone.

For chemical or gaseous products, specialized berths, located on the Le Havre Grand Canal, are accessible to ships of up to 70,000 tons. These make the reception and re-expedition of hydrocarbons and various chemical products as well as gases such as butane or propane possible. 13 specialized berths are set up in the Industrial Zone to ensure this traffic which directly supplies the important petro-chemical activity in the region of the Lower Seine.

II.1.2. - Facilities for Solid Bulks

The principle solid bulk trades of the Port of Le Havre include coal, cement, fertilizers, grains...

Dry bulks are treated in specialized facilities, operated either by the Port Authority, licence-holders, or private companies.

The berths must be able to receive ships of various sizes, from 150,000 tons for coal to 30,000 tons for cement.

II.1.3. - The Reception of Dangerous Goods in Non-Specialized Facilities : the Case of Container Terminals

The Port of Le Havre has installed five container terminals, three of which are located in the Tidal Basin. A considerable investment program has been undertaken in order to continue the development of facilities for the reception of container trades.

The various terminals are equipped with 19 40-ton gantry cranes allowing for the handling of all types of containerships.

This type of traffic makes the installation of vast storage yards (several hundred hectares) necessary for the reception of boxes.
Presently, the largest containerships can carry up to 4,000 boxes.

One can estimate that 20 to 30% of all containers contain goods which are more or less dangerous for the environment.

These goods are well-protected in the container, but it is difficult to identify the nature of the goods, and, consequently, the corresponding risks for each container, whose identification is too often limited to a simple number.

The computer systems used do, however, allow us to locate containers which may present a risk for the environment.

However, the containers remain, except in the case of particularly dangerous goods which have been identified, dispersed on the ships and in the storage areas.

II.2. - The Main Risks Linked to In-Port Transit of Dangerous Goods and Preventive and Curative Measures in Pollution Control and Disasters

It is not possible to do an exhaustive study here on possible risks and the means necessary for prevention and control.

Dangerous goods Nomenclatures have been set up and completed by specific recommendations according to the class of products and the products in each class.

The IMDG Code (International Maritime Dangerous Goods) published by the IMCO (Inter-Governmental Maritime Consultative Organisation) makes up the basic collection of safety measures applicable to the transport of dangerous goods on waterways.

Very briefly, it is possible to envisage three main types of risks applicable, for example, to certain goods:

- fire (hydrocarbon, coal, cotton)

- explosion (gas, hydrocarbons, grains, sugar, ammonia, nitrates...)

- water pollution (hydrocarbons, chemical products)

However there are other risks (radioactivity, toxicity, atmospheric pollution...).

In the same vein, it is possible to differentiate between means relevant to passive security and fixed means, on the one hand, and those relevant to active security and mobile means, on the other hand.

Retaining tanks, gas detectors, heating detectors...belong to the first category.

In the second category, we can cite classic fire-fighting means as well as tugs equipped for fire-fighting and pollution control, booms, dispersal products, mobile storage tanks.
III - The Organization of Safety and Pollution Control

In the Port of LE HAVRE, a Managing Director, the Director of the Port Authority, is in charge of the management and operations of the port.

His role is decisive in setting up and operating emergency means.

The port zone is a complex environment within which many professions and participants, often from outside the port, interact.

In addition, in the cycle from the fabrication to the use of dangerous goods, transport, and, more precisely, the rupture of port responsibility, is a weak link.

Thus any accident in a port must, a priori, be considered important, or possibly important, as the first emergency decisions are often those which decide the future seriousness of the pollution or accident.

It is thus necessary to have precise pollution and accident prevention and control plans which are capable of advancing easily through progressive stages, involving increasing responsibilities according to the seriousness of the problem.

III.1 - Pollution Prevention and Control

As for ship reception, prevention must be considered on two levels:

- the design of facilities and equipment, aiming at optimal safety,
- operating conditions in the port.

International agreements, to which most of the large industrialized countries are parties, lay out the conditions for ship passage in ports and, notably, specify the accommodations which must be available to them.

The "MARPOL" Agreement calls for the presence of facilities for the reception and treatment of polluted water (in particular, ballast water from tankers) as well as solid waste from ships.

Concerning the organization of pollution control measures, they are controlled by national regulations.

French regulations are based on a specific set of regulations called "POLMAR".

French territory is covered by plans called "POLMAR Land" and "POLMAR Sea" which envisage various scenarios and specify the means to be mobilized (public means and if necessary the requisition of private means).
POLMAR PLAN

AF/MAR

PORT AUTONOME du HAVRE - Capitainerie -
(Port du HAVRE - Port d'ANTIFER)

Sous-Préfecture
LE HAVRE

PREFECTURE

CIE GEND
ou P. U.

Gpt de GEND
ou D.D.P.U.

CODISC
(PARIS)

C.S.P.

D.D.S.I.S.

SAMU

message POLREP

authorité à autorité
voie opérationnelle

- PREMAR 1 et CROSS/Ma
- Ministères concernés
  (si déclenchement Plan POLMAR)
- éventuellement, départements voisins (EURE-CALVADOS)
Equipment storage centers are set up along the coast and high-level training exercises are regularly organized by the State Maritime Services.

For small- and medium-scale pollution within the port, the Port Authority has its own means (equipment and personnel) which allow it to act with maximum flexibility (speed and efficiency). Agreements and treaties with port services (Pilots, river pilots and towage) provide for supplementary equipment to be put under the operational authority of the Harbour Master.

III.2 - Prevention and Control of Accidents

On a national level, for very large disasters of the catastrophe type, the State and its local representatives, the Prefects, put the emergency plan "ORSEC" into operation. This plan combines all functional and operational orders which provide for the organisation of emergency means and the management of the crisis.

We should note here that this aspect of the management of major crises, following the SEVESO catastrophe which caused a European order meant to prevent catastrophes, has taken on more and more importance.

The relation with the media, in order to be efficient, that is, objective, coherent and controlled, must be correctly prepared.

Improvised actions may in fact, have a negative effect which go largely against the public interest.

In applying the SEVESO Order, risky activities must have emergency plans (specialized emergency plans such as cordonning-off plans, internal operations plans for facilities at risk, particular plans covering the problems created outside facilities at risk).

Various plans are thus in place to manage all problems which may touch either the ship in the port, a port installation, or an industrial facility.

In particular, they provide for various alert levels and the mobilization of means, depending on potential risks and the manner in which situations develop.

The Port of Le Havre Harbour Master’s Office, operational 24 hours a day, which ensures the direct surveillance of the entire zone and has the means necessary for transmitting information, is the mandatory point of passage for alerting the entire Le Havre area.
SAFETY PLAN

ETABLISSEMENT INDUSTRIEL
A L'ORIGINE DE L'ACCIDENT

VIGIE DU PORT

SAMU 6715
Autres CSP
Préfet - Dir. Cabinet
Préfet Dir. Séc. Civi.
D.D.E.
D.D.P.U. ROUEN
Cdt Gpt de gendarmerie

Pompiers 6718 ou 18.
066. Secu 7384 ou 8009 ou Astr.
Service U
S/Préf. 6617
Off. Sect. VHF ou télè.
POLICE 6717
Gendarmerie

SAMU 6715 ou 6718
Cdt de Port
Dir. des Opérations portuaires
Dir. Général
D.R.I.R.
S.N.C.F. 8234

Base hélaco
Autres SAMU
Médecins Urg. Secouristes
Hôpitaux
IV - The Development Plan and the Charter for the Environment

The decision to set up a Port Industrial Zone in Le Havre was a national decision based on general development plans which may not be put into question, except by governmental decision.

On the local level, urbanism documents drawn up by local representatives reiterate the general provisions and confirm the port and industrial vocation of the entire zone (which covers 8,000 hectares).

The unity of the zone in terms of development is thus preserved. In addition, the responsibility for its development is granted to a single organization, the Port of Le Havre Authority.

However, it appears more and more evident that industrial and port development must take the environment into account.

The Port of Le Havre Authority has thus been led to draw up a development plan notably describing the principle directions of industrial and port development in the medium and long term.

Locally, this plan has been the result of a very wide cooperation associating public representatives, economic circles, associations, manufacturers, State Services.

The main objectives of the plan are:

- to provide for almost instantaneous decision-taking for a project of industrial construction or extension,

- to take into account the preservation of certain natural environments to be preserved (the central part of the Estuary),

- to incorporate, as early as possible, a consideration of the technological risks by examining, in particular, the compatibility between certain risky activities with areas where there is a high concentration of people (factories with large work forces, roads with heavy traffic...)

- to guarantee industrial and port development by simultaneously making the plan a reference document for the official city planning regulations which guarantee the control of urbanization and a communication tool for industrial and port promotion activities.
In order to complete the plan and to draw up guidelines for action and procedures, a charter has been drawn up. The charter describes the conditions under which the development plan is to be carried out. It deals extensively with concerns about the preservation of zones presently in their natural state which must either be upgraded or preserved in the expectation of their eventual conversion for industrial or port uses.

The charter also invites port personnel and the partners of the Port Authority to learn and think about the protection of nature and to participate in training programs designed to improve the relationship of the port with its environment.

**Conclusion - The Stakes**

The Port of Le Havre’s goal is to confirm its position among the large European ports. Of course, this objective is reinforced by economic arguments.

However, it is becoming more and more obvious that safety and environmental protection will present important advantages.

Technological changes, both in ports and in industry, improve efficiency and reliability.

The development and the operation of a port, and even more so of an industrial zone, thus implies the implementation of complex systems, which are not always easy to interconnect.

Data processing is an important tool in the creation of efficient organizational plans.

However, the concentration of large quantities of dangerous products on ships, in the port and in factories still presents, in particular in the two first cases where the environment is very variable and complex, a serious problem for present-day industrial societies.

In the eyes of public opinion, accidents are not very well tolerated and catastrophes are always inadmissible.

It is thus important to take preventive action as much as possible by offering facilities which provide the best safety guarantees, both in terms of development and current operation rules.

Emergency plans allowing for the mobilization of the necessary means, that is, both equipment and personnel, must be envisaged for all possible cases.

The prevention of accidents and the possibility of putting pre-existing plans for intervention into force in the case of problems guarantees the credibility of those in positions of economic and political responsibility.

They guarantee the quality of life for future generations.
Environmental management in ports
P.H. Olson

Summary

This paper generally deals with the environmental problems that could be expected to become future problems of the port and shipping industries. It also gives suggestions on how to solve some of these problems.

Three main areas are covered. They are:

1. Hydrocarbon emissions when loading petrol into tankers.

   Oil depots are often situated close to populated areas and as hydrocarbons are ventilated to the air when loading, more and more ports are required to collect and process these hydrocarbons.

2. Exhaust gas emissions to the air and noise from ships in the inner harbours of ports.

   Environmental authorities are requiring ships to connect to shore electricity while in port to reduce air pollution and noise from auxiliary engines of ships. The paper gives aspects on this and suggests better methods to reduce pollution.

3. The reception of ship generated wastes in ports.

   The MARPOL 73/78 Convention regarding reception of wastes is not effective in third world countries, not because ports can not build and run reception facilities, but because the ports can not get rid of the wastes they may collect. The most important reason for this being that these countries lack proper waste management systems.
The author sees the reception of garbage as the biggest future problem when it comes to the reception of ship generated wastes. Ports will require garbage to be separated onboard. The convention does not cover this, and ports are now setting up their own standards, which then will vary from one port to another. The paper offers a suggestion on a separation standard and the author pleads with naval architects to set ample space aside onboard ships when constructing new ships in order that garbage may be separated and retained onboard.

Background to the port environmental policies

Most ports were originally constructed in sheltered bays or riverbranches which could give both weather protection to the ships and be fortified against those who wanted to lay their hands on the ships and their valuable cargoes. The ports gave job opportunities to people, attracted commerce and gave protection against malicious gangs of robbers or belligerent nations. Therefore, cities grew up around the ports.

Environmental aspects were neither thought of nor imposed any problems in those days. As ports expanded outside of their city boundaries the population followed, building their houses close to the new port areas. Industries took advantage of the proximity of the cargo handling facilities or were located there by the city counsellors who dedicated these new port areas as industrial sites. Roads and railroads were constructed to serve the new premises, etc.

Most of this expansion took place in our generation and is still going on. The environment was indeed thought of when the big liquid bulk cargo and container terminals were constructed, but the heavy expansion in the transportation of dangerous chemicals and other harmful substances was not anticipated. This traffic gave rise to safety and environmental problems in and around the ports. Neither was the growth in the heavy truck-traffic and the problems it creates nor the problems associated with the bigger and bigger ships thought of.

Due to the change in packaging of general cargo from crates or palletized goods into containerized the traditional handling
and storage areas in the inner harbours of the ports became too small. The ships also grew larger and their draft became too big for the old harbour basins. The goods was moved to the container harbours and many old parts of the ports became obsolete. Some of them could, however, be used for passenger vessels like cruising ships or large ferries. The draft of these is usually not as big as the draft of cargo ships. Other obsolete port areas in the middle of cities were, and currently are, being turned into housing areas. One could think that this would solve the environmental problems of the inner harbours. But not so. Passenger ships need a lot of electricity also while in port. They therefore have to run their auxiliary engines and these produce exhaust gases and soot apart from creating noise.

The first generation of people who choose to live close to the port terminals often had some connection to the ports. They accepted noise and other troubles. The next generation, which had little or no connection with the ports at all would, however, not accept this. They demanded the ports to be clean, silent, nice and perhaps even picturesque.

In ports we will find almost all the environmental problem areas of our modern society. They will be: soil pollution, water pollution, air pollution and noise. However much I would like to talk about all this and what measures ports take or should take to solve the problems, time restricts me from doing so.

What often enough is not thought about is that safety and environmental protection in ports goes hand in hand. Most of the environmental problems are found in oil and chemical ports and terminals. If one wants to make an improvement to the environment in such a port or terminal it must never be done at the cost of the safety, because if safety is set aside one is very likely to end up with an environmental disaster. It may sometimes be very difficult to convince politicians and environmental authorities that some of their “good” ideas could be dangerous. Having been working with these matters for many years I have come across too many horrifying examples.

**Hydrocarbon emissions to the air when loading tankers**

The first of the three port environmental areas I intend to
address is hydrocarbon emissions when loading petrol into tankers. This will most probably be the future problem of those petrol loading ports who have not already come into contact with it, which is the majority. As tankers are involved, it will also be a problem for shipowners, because tankers not complying with the demands ports and oil companies will raise in the future will probably have to seek business somewhere else.

When loading tankers they have to breathe out. If one does not allow that, they will take revenge by bursting, and that is indeed unpleasant. When loading petrol approximately half a kilogram hydrocarbons will escape per ton being loaded. As we don’t want to inhale these substances something has to be done. Cars run on hydrocarbons, people do not. So the hydrocarbon gases have to be taken care of in some way.

There are already quite a few ports around the world where the gases have to be brought ashore for processing and more will follow. But there are a lot of problems involved in doing that in a safe way. Petrol tankers must, of course, have connection points for the vapour return lines, like chemical carriers have, so the technique is there. The problem is more on the shore side, because shipowners do not want accidents ashore to affect their ships and terminal operators do not want accidents in their terminals.

Hydrocarbon mixtures in air may be explosive if the concentration is the right one. The International Maritime Organization, which is the United Nation’s organization for the safety and environmental protection of the seas, is currently discussing the safety problems. As always, there are several options. The tanks could be inerted before loading or flame arrestors and explosion traps could be inserted in the shore pipeline system, or both methods could be used. There are also talks about enrichment or dilution, but from a practical point of view I do not see them as being feasible.

What do we do when we have brought the gases ashore? The simplest thing would be to burn them in flames like the ones you may see in petroleum refineries. But oil port people are a bit worried about flames, and besides, they are not the best for the environment, so that may not be such a good idea.
There are a lot of other ways to deal with the hydrocarbon gases. I will not try to cover all the methods but there is a Danish invention that is widely used not only in ship loading applications but also when loading rail and road tankers. It is called Cool-Sorption. The principle behind it is quite simple. The gases are sprayed with cold kerosene on which the hydrocarbons are adsorbed. The kerosene is then heated giving off the petrol hydrocarbons in a liquid form. The petrol is returned to a storage tank and the kerosene reused. Cool-Sorption even claims that after a couple of years, when the capital costs are paid, you will be able to make a profit on the petrol recovered. This method, it is said, has been shown to give a better result than refrigeration, compression, etc. At least 95 per cents of the hydrocarbons are recovered.

Let us now leave the oil port problems and discuss other headaches ships give port authorities, still keeping air pollution in mind.

Exhaust gases from ships in ports

In my introduction I mentioned that passenger vessels in the inner harbours could create some problems as they have to run their auxiliary engines to produce the electricity needed for kitchens, air conditioning, lifts, illumination, etc. They create noise as well as pollutive exhaust gases and soot. People living in the neighbourhood of passenger terminals often complain about this. Ferries are usually not berthed for such a long time, but when they load and unload cars and cargo over their ramps people are also disturbed by the noise from the ramps as well as the noise from the diesel engines of lorries and buses, especially if this takes place during the night.

What are we going to do about this? Well, politicians in the city where I come from had a solution to these problems: “Connect the ships to shore electricity while in port!” They went on by saying, that all ships staying more than two hours should be connected. They probably made a comparison with cars who may not run their motors on idle for more than one minute, so two hours was generous!

An important drawback when ships are connected to shore
electricity is that, as the engines cool down when shut off emissions will be very high for a considerable amount of time after restart. It has been calculated that it takes about five hours for a modern large passenger ship to get emissions down to the same level as they were before the engines were shut off. This, of course, means that shore connection even may be disadvantageous to the environment.

An emission source that shore connection will not affect is the main engines. They and the auxiliary engines have to be used when ships are at sea or maneuvering in port. The only way to cope with these problems is by dealing with the exhausts. One could either do something to the engines or to the fuel oils or to both.

The simplest way to bring down emissions is to use a better quality of fuel. Almost all big passenger ferries calling at Swedish ports nowadays use a fuel oil for their auxiliary engines with a sulphur content of 0.5 per cent or less. Bunkering oils for main engines may have a sulphur content from 0.8 up to 6 per cents. The ferries I mentioned usually burn an oil with a sulphur content of about 1 per cent in their main engines.

When it comes to measures to the engines there are a number of ways to deal with them. Engines may be constructed in such a way that they become more efficient in relation to the quantity of oil they burn, catalytic exhaust cleaning devices may be used or filtering devices may be fit to the exhaust outlets, etc.

Yes, we do use shore electricity in a couple of places in Sweden. In Stockholm the very big passenger ferries sailing to Finland connect to the city main and in Gothenburg equally as big ferries to Germany also connect.

The reason for shore connection in Stockholm was to reduce the noise from the auxiliary engines which disturbed patients of a nearby hospital.

In Gothenburg the air is said to be extremely polluted, which is an exaggeration that some local environmental movements have succeeded to convince people of. However, I have to admit that
a couple of days of the year Gothenburg suffers from inversion. This happens on cold winter days with low temperatures. During these cold days the ferries are not allowed to use the shore electricity, because the city can not supply enough. It has to be used for heating purposes.

One would think that these days should be the ones when it would be of the greatest importance to use shore electricity onboard ships. Well, it is not. The oil burnt in the city's electricity works is of a lower grade with a higher sulphur content than the one the ferries use for their auxiliary engines. The bizarre fact is, that when these ferries use electricity from the shore they add to the pollution of the air over the city. But the public does not know this, so the situation is now in a quite happy state.

There are a lot of obstacles that have to be overcome if one wants to connect a ship to the shore mains. First of all there is no place onboard to plug in the connection cables. Secondly, most ships use 60 cycle electricity while many countries only deliver 50 cycles. The power requirements for some type of ships are very high and the supply may not be enough. One will need big transformers close to the ships and they will obstruct the quays. Cables must be kept short to reduce losses and they are heavy and difficult to handle. Due to differences in ships' sizes there have to be numerous connection points in a big terminal. Connection must be done in phase by skilled electricians. If something goes wrong, computers and navigational instruments onboard will get out of order.

My message is, if anyone should be dreaming about ships' connecting to shore electricity, stop doing so. There are much better and easier ways to cope with the problems.

Both the Baltic Marine Environment Protection Commission and the International Maritime Organization are currently dealing with the problem of air pollution from ships. The emissions have been found to be of a much bigger magnitude than earlier was anticipated. I think that in the future we will see standards for better marine fuel oils. It would be better to use high grade oils onboard ships and burn the lower grades in power stations ashore where efficient exhaust gas filtering devices could be installed.
To finalize the point on problems associated with ferries in inner harbours, let me just say that the noise when heavy cars are passing the ramps of the ships can be much reduced. Rubber bushings could be introduced in the hinges of the ramps and the part of the quay where the ramps are landed could be covered with a soft material that will check the noise.

Reception of ship generated wastes in ports

My final item of this paper is problems related to the reception of wastes from ships.

You may have heard about the MARPOL convention or the International Convention for the Prevention of Pollution from Ships 1973 with Protocol of 1978, which is its proper name. The convention stipulates what kind and quantities of wastes ships may discharge into the sea taking into account the environmental sensitivity of different sea areas, how ships shall be equipped, etc. The convention also stipulates that reception facilities for wastes that are not allowed to be discharged into the sea shall be available in ports.

The reception is, however, not the problem. It lies in what to do after the wastes have been collected in the ports. It may sound fine to have reception facilities, and it works fairly well in ports in highly developed countries. But in the rest of the world the situation is somewhat different. Reception facilities are costly to build, people do not know how to run them and they are not acquainted with the special safety regimes governing the reception of wastes with regard to certain kind of ships and cargoes. But most important, ports can not just collect the wastes and store them. If they should do that they would very soon end up with an enormous environmental problem apart from a lack of cargo handling spaces. Subsequently, reception facilities are not built in these parts of the world. Ships have to keep their wastes onboard until they reach a port where they can get rid of them in a lawful way or discharge them overboard in an unlawful. This creates a very big problem to the ships.

To raise money for building reception facilities is, of course, quite a problem of its own. I will not address that one, but
there are ways. To produce guidelines and train personnel on how to use the facilities is another, but there are consultants like myself who would be very happy to help out. The third problem, how to deal with the wastes collected is the big one, and therefore I will elaborate a bit on that.

The countries we are talking about usually do not have any waste management systems. Garbage is often dumped outside the cities on big dumps where thousands of people are trying to find something useful. Sewage is let out into the sea and oily wastes may not be treated in any other way than draining away the water. They are then used for heating purposes and exhaust gas cleaning has probably never even been heard of.

What first of all is needed is to introduce an environmental consciousness among the people in these countries and to convince their governments of the advantage of waste management. This is more easily said than done.

Now, let us assume that we have succeeded in these two tasks. I may then turn to the practical part of the reception of wastes from ships. Let me start with the oily ones. They can be divided into ballast water, tank wash water and engine room wastes, the latter consisting of sludge from fuel and lubricating oils and oily bilge water.

As oil is usually loaded in refinery ports and ships then have to get rid of their dirty ballast or tank cleaning waters when they arrive at these ports the problem is really not so big. Refineries are usually equipped with oily water separators to clean their oil contaminated storm water. These separators can, of course, also handle oily water from ships. It is merely a task of conveying the oily water from the ship to a magazine where it is stored until it can be processed in the separator. The technique is simple and well known. I have often enough met the misconception that ship generated wastes are something mysterious that have to be dealt with in a very special way, but that must not be so.

To overcome the high costs of using these facilities, the best way, in my mind, would be to let companies who are loading tankers be responsible for providing the reception facilities. That should even be done free of charge to the ships. The
shippers will in any way have to pay for the discharged water, so why not let them do right from the start? They will then do what they can to keep costs at a minimum and hopefully also to be efficient. In this way port authorities will not be involved, which also will keep costs down and efficiency up.

Engine room wastes like sludge and oily bilge water have to be received by the port authorities, as these kind of wastes arise in all kind of ships. Engine room wastes could also be processed in refinery separators, even if this is not the best way of doing it. Lube oils contain a lot of harmful substances that will pass an ordinary separator, but it all depends on what equipment one may afford to invest in. Due to economical restrictions one may not be able to go for the best possible solution at once. It would, however, be better to do it this way than not to do anything at all and end up with the engine room wastes going overboard.

Sludge and bilge water is quite easily received by the means of tank trucks or barges, so the reception facilities are not too expensive.

Chemical carriers should discharge their tank cleanings in the unloading ports. The consignees should provide the facilities as they may be able to use the residues in their industries or have the means to deal with the tank cleanings as they probably also would get the same wastes from their own operations.

Sewage may create a problem in ports where the municipality has not got any sewage treatment facility, which they usually don’t have in developing countries. Sewage may, however, be discharged to the sea in most sea areas of the world excepting in some so called “special areas”. Modern passenger ships often have treatment plants onboard. In Sweden we have, however, seen that big ferries do not like to pump their sewage overboard even if they are allowed to do so, because environmental cleanliness nowadays is part of the ferry companies popular relations concept. They have found out that if they can show an environmental consciousness they will gain in business. The ferries connect to the municipal systems while in port and the sewage is pumped ashore. One problem is, however, that the shore systems often are not dimensioned for the high discharge rates of big passenger vessels only staying in port for a short period.
of time. Sewage has been taking other ways than through the underground pipeline systems with some unpleasant consequences.

The waste that in the future will create most of the problems both to ships and to ports will be the garbage. Today almost all kinds of garbage except plastics, synthetic fishing nets, ropes made out of man made fibres and the like may be discharged into the sea under certain conditions.

I am quite sure, that discharges of garbage will become more restricted in the future. Governments will prohibit discharges in their territorial waters, more and more areas will become "special areas", etc. My guess is that discharges outside "special areas" also will become more restricted. Apart from this, the coastal traffic already has to discharge most of its garbage to shore reception facilities according to the requirements of the convention.

Some ships' generated garbage like food wastes, some cargo associated wastes and infectious wastes from sick-bays should not be disposed of in dumps or landfills as diseases and foreign vermins may be spread. These wastes should preferably be incinerated. However, I do not think that the incinerators should be owned and run by the port authorities. They are costly to build and complicated to operate. They also need a constant flow of garbage to work well. The ports will probably not receive enough to feed them, so they should serve the community around the ports as well as the ports themselves and probably be operated by special companies.

Incinerators also need a lot of fuel, and some of this may consist of the sludge and other waste oils ports have received from ships. Exhausts from the incinerators should, of course, be cleaned.

The second best thing to do with garbage if incineration is not feasible is to deposit it in a safe place and spread lime stone over it.

Garbage that does not need incineration or other complicated means of processing may be dumped or used as landfill.
As different kind of garbage has to be handled and processed in different ways, ports will require the garbage to be separated prior to discharge. The problem is, however, that the convention does not say anything about separation. I have noticed that different ports often have different separation criteria. They depend very much on the different handling and processing techniques of the ports communities' processing plants.

If something is not done very quickly we may end up with a situation where ships are required to separate their garbage in a different way for almost every port of call. Of course, ships can not meet these requirements, and the garbage will subsequently be discharged into the sea.

What is needed is first of all an international regulation on garbage separation onboard ships. Shipowner and port associations should take part in the creation of this regulation. The processing plants shall then have to comply with it.

Secondly, ships need storage compartments for the garbage. When new ships are constructed this should be thought of in order that ample space can be set aside onboard.

The separation itself is a lesser problem. Different kind of wastes arise in different parts of the ships and this fact could be used. Garbage that has to be taken ashore should at least be separated into the following categories:

a) combustible garbage;
b) non-combustible garbage;
c) environmentally hazardous substances, like leftovers from solvents and paints, oily rags, batteries, accumulators and flourocent lamps; and
d) infectious materials and medicine residues.

There are, of course, a lot of other problems ports may encounter with regard to the environment. Various ports have also found good solutions to many of them. What I now have tried to outline are some of the major ones and the ones that can be envisaged to be problems for a great number of ports as well as for ships in the near future – if they are not already.
Summary

One of the tasks of the Rotterdam Municipal Port Management is to ensure safety and expediency of shipping. This multiple task presents itself in a rather dualistic way, e.g. safety criteria dictate strict tidal windows that, in their turn, generate waiting time for shipping. In optimizing the safety system both factors should be evaluated.

The paper presents some results of the study "Safety as a product" and focuses on the setup to provide an overview of all cost aspects in safety evaluation. Attention will be paid to the methodology of the study and results will be presented for the following cost components:

- cost of safety systems;
- damage cost of vessels;
- damage cost of infrastructure;
- waiting cost of vessels due to:
  - tidal and wind restrictions;
  - non-availability of nautical services.

The main cost factors will be determined and ways will be sketched to reduce their impact.
1. SHIPPING POLICY OF THE ROTTERDAM MUNICIPAL PORT MANAGEMENT

One of the key functions of the Rotterdam Municipal Port Management consists of providing nautical services. The main objective is: supporting the economical process by realisation of an efficient navigation in the port, under the conditions of a sufficient safety level and limited environmental effects. This objective is strived after by operating an optimized nautical infrastructure and by means of an effective information process.

Safety is usually considered in terms of risk and thus as unsafety. Unsafety is counterproductive. Incidents result in obstructions in the logistic chain. From this follows that reducing unsafety prevents the loss of money due to damage or delay. This is a conclusion somewhat different from the view of permanently reducing risk. Below a certain level of risk - in terms of probability of an accident - it is not useful to decrease this probability even further.

Safety inherent to the system, coming from procedures adhering to the use of regulations and of proper material, results in an improvement of the system's efficiency. However, in everything the human factor is essential. That is why the Rotterdam Port Management considers safety as a product: for safety is the result of people making an effort to handle things properly, showing a responsibility to prevent accidents and if accidents do occur having the knowledge, training and equipment to minimise the effects.

Following our main device it is clear that safety is no goal in itself but has to be evaluated together with other interests. This implies that a certain degree of risk has to be accepted. The key question is: which level of risk is acceptable. The appropriate framework for answering this question should be found in a safety policy.

In accordance with the overall objective of the Rotterdam Municipal Port Management (promoting activity in the port and the industry), three safety objectives have been defined:
- internal safety: to maintain a sufficient level of safety within the port;
- external safety: to maintain an acceptable level of risk to the public
outside the port area;
- long-term safety: to maintain such a water quality in the port that sludge can be dredged without any restrictions.

Looking into more detail, the following objectives can be specified:
- prevention of accidents within the port;
- limitation of the effects should accidents occur.

A further categorization proves to be useful:
- "daily" accidents, characterized by a high frequency and small effects;
- large scale accidents, characterized by a low frequency and major effects;
- catastrophies, characterized by a very low frequency and enormous effects.

These accident categories have their own prime instruments in the overall policy:
- for "daily" accidents physical planning is the main instrument. Prevention is rather difficult, so the effects can be limited by zoning as an instrument to separate port activities and urban areas;
- large scale accidents should be prevented as much as possible and the effects should be limited by scaling the incident fighting organisation and equipment to this type of accident;
- catastrophies should be prevented.

Obviously the three types of accident do have an interdependency. Prevention for one type will have its beneficial effects on the other types, the instruments to limit the effects do work throughout the chain.

Safety can be seen as divided into four aspects:
1. Safety of the shipping traffic
2. Safety in the transport of dangerous goods
3. Safety of the (marine) environment
4. Occupational safety.

The present paper deals with the safety of shipping traffic.
2. SHIPPING TRAFFIC IN THE PORT OF ROTTERDAM

2.1. The approach to the Rotterdam Port area

Sea-going ships approaching Rotterdam are obliged to notify 24 hours before ETA to the Port Authorities. Dimensions and cargo determine whether a sea-going vessel is obliged to have a pilot on board. Ships with a draft of over 65.5 ft. must use the Euro-Maas channel.

All ships with dangerous goods on board have to notify this separately, also 24 hours before ETA. For inland vessels this applies only when a limited category of dangerous goods is on board. This means that in comparison to the situation for sea-going ships only a small number of ships is notified.

2.2. Ship movements

The number of different types of ships which entered the port of Rotterdam in 1990 are presented in the following table.

<table>
<thead>
<tr>
<th>Type</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry bulk carriers</td>
<td>1,891</td>
<td>5.9</td>
</tr>
<tr>
<td>Combination carriers</td>
<td>275</td>
<td>0.9</td>
</tr>
<tr>
<td>Crude oil tankers</td>
<td>1,246</td>
<td>3.9</td>
</tr>
<tr>
<td>Tankers</td>
<td>4,417</td>
<td>13.7</td>
</tr>
<tr>
<td>LPG/LNG carriers</td>
<td>399</td>
<td>1.2</td>
</tr>
<tr>
<td>General cargo</td>
<td>15,648</td>
<td>48.7</td>
</tr>
<tr>
<td>Full container ships</td>
<td>3,143</td>
<td>9.8</td>
</tr>
<tr>
<td>Ro-ro</td>
<td>2,301</td>
<td>7.2</td>
</tr>
<tr>
<td>Passenger ships</td>
<td>1,138</td>
<td>3.5</td>
</tr>
<tr>
<td>Others</td>
<td>1,697</td>
<td>5.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>32,155</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 1: Number of sea-going vessels entering Rotterdam in 1990
The number of general cargo ships dominates this list, which can be explained by the role of the smaller size ships that are very common in the category of general cargo ships.

The fluctuations in the number of sea-going ships that enter Rotterdam each year are relatively small. The number of ships entering the area at Maasmond varies around 33,000 per year; this results in some 76,000 ship movements.

Each year approximately 120,000 inland barges visit the port of Rotterdam; this results in about 300,000 shipmovements. The average load capacity increased considerably over the last nine years, 3 or 4% per year. So, with an almost constant number of ship movements the trade volume has been increasingly expanded. Approximately 30% of the barges going to Rotterdam is loaded, in the departing trade approximately 80% is loaded.

The traffic densities in the port of Rotterdam are presented in the next figure.
In the past years there has been a change in the destination of ships in the port area. Remarkable is the fastly increasing part of the traffic to the Maasvlakte and, to a smaller degree, the increase of traffic to the Europoort area. There is a decrease of traffic intensity in the eastern part of the area. In total, the whole picture reflects a shift of port activities westward, towards deeper water.

In the sea-going traffic there is a great difference in the traffic density over the day for the incoming and outgoing direction. For the outgoing ships the pattern is determined by the working hours of the terminals which results in a peak shaped graph. For the incoming ships the pattern is much smoother.

It further appears that the pattern is strongly dependent on the ship size; the variation in the traffic density decreases with increasing size.

3. SAFETY AND EFFICIENCY IN SHIPPING TRAFFIC

3.1 Introduction

It is realised internationally, that nautical safety cannot be separated from efficiency of navigation. Measures taken to enhance safety can at the same time reduce or enlarge the efficiency of shipping traffic. So, next to safety the efficiency will have to be addressed in a safety policy.

There are various parameters influencing safety and efficiency of navigation. Apart from regulations and infrastructure several nautical services can be mentioned: pilotage, VTS (Vessel Traffic Service), patrol vessels, tugs, aids to navigation etc. Most of these safety means are privately operated; the VTS and patrol vessels are under the competence of the R.M.P.M.

Because the port management has various - partly overlapping - nautical services at its disposal, it is necessary to determine which combination of means under a prevailing safety standard makes the nautical key function available in the most efficient way.

Safety is usually expressed as risk, in probabilities of accidents and the size of
their effects. However, it is often unknown which level of risk is acceptable.
In our opinion it is perhaps more uniform to express nautical safety or unsafety
in damage or the financial consequences of an accident - i.e. immediate damage
to ship or infrastructure as well as consequential damage due to the blocking of
shipping traffic and environmental effects.

Doing so it will be possible to evaluate the efficiency of the various nautical
safety systems by analyzing costs versus profits. Thus, costs are weighed in
terms of decrease of damage and increasing efficiency by reducing waiting
periods of ships.

3.2 Nautical accidents

With respect to the accidents that affect the nautical safety, the following types
are considered: collisions between ships, collisions with port infrastructure and
grounding or sinking of ships.

Approximately 75% of the accidents are collisions of a sailing and a moored
ship or a ship colliding with an object (i.e. a quay, jetty, bank, lock or bridge)
or runs aground.

The following table of the distribution of accidents after location shows an
obvious relation between accident type and location.

<table>
<thead>
<tr>
<th>Collision type</th>
<th>Fairways %</th>
<th>Basins %</th>
<th>Total %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 sailing ships</td>
<td>10</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>Sailing/moored ship</td>
<td>9</td>
<td>29</td>
<td>38</td>
</tr>
<tr>
<td>Ship/object</td>
<td>17</td>
<td>20</td>
<td>37</td>
</tr>
<tr>
<td>Others</td>
<td>4</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>41</strong></td>
<td><strong>59</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>
Most of the accidents take place in the harbour basins; it concerns practically only accidents in which a sailing ship hits a moored ship or an object. On fairways, in comparison, also a remarkable part of the accidents is due to two sailing ships colliding.

For fairways a further study has been made to locate (possible) accident concentrations, as can be seen at the following figure:

On the Nieuwe Maas/Waterweg there are obviously two important accident sensitive areas:
- at the river near the city bridges and the mouth of the Maas- and Rijnharbours, and the branching of the Oude Maas.
- on the Oude Maas especially the area around the Spijkenisse- and Botlekbridges is sensitive to accidents.
Almost 60% of the accidents take place during winter because of the adverse wind- and fog conditions in that period. The possibility of an accident under conditions with strong wind or limited visibility is considerably larger than under normal conditions. For example, before installing the new Vessel Traffic System, the probability of an accident with a visibility of less than 500 meters is four times higher than with a good visibility.

Most of the accidents have minor consequences. Only 15% of the accidents is severe, implying noticeable damage to ship or cargo. This type of accident occurs comparatively more frequent in collisions where 2 sailing ships are involved. With increasing speed differences of ships at the time of the collision also the probability of heavy damage increases. On fairways in 17% of the accidents 1 or more ships is noticeably damaged, while in harbour basins this is 10%.

3.3 The cost of accidents

The most important components of cost as result of nautical accidents are: damage to port infrastructure and damage to ships. To get a complete picture also consequential damage should be encountered. However, this type of costs is hardly quantifiable as yet.

The total damage to municipal properties (quays, piers, jetties etc.), governmental properties, privately owned quays and jetties and ships, resulting from nautical accidents can be estimated at roughly f 20 mln per year.
3.4 Delay costs

In a shipping system turn-around and delay are important. The quality of the system can be measured by comparing the present situation to an ideal situation whereby any ship can enter or leave port any time. Of course, only the waiting times connected to the use of the nautical infrastructure are considered.

The most important components of those waiting periods are: waiting as a result of the application of an admission policy and those as a result of no pilotage.

For less than 5% of the ships visiting Rotterdam there is an admission policy due to tidal restrictions:
- the Europoort/Maasvlakte area is always accessible for ships with drafts less than 65.5 ft.
- ships with a draft of over 65.5 ft can use the Euro-Maas channel only during a certain period of the tide. The length of this tideframe depends apart from the ships dimensions on the expected swell and water level.
- an admission policy is also applicable for the Botlek and 1st, 2nd, 3rd Petroleumharbours and Waal-/Eemharbour. The length of the tideframe depends per harbour on the actual draft of the ship, ship length and type. Only 5% of the ships visiting these basins has tidal restrictions.

The vast majority of the vessels that are subject to delays (about 15% of all visiting vessels) have an average delay time of one hour or less. About 5% of all vessels wait more than one hour, due to admission policy and suspension of pilotage.

To get an insight in the effect of delay, the delay is expressed in terms of turn-around time. The following figure shows that the average turn-around time is about 24 hours. Delay accounts for somewhat more than 2% of the turn-around time.
Although delay accounts for a very small increase in turn-around time for each individual vessel, for the total number of vessels visiting Rotterdam the cost is considerable. It amounts to between $15 and 20 mln per year.

3.5 Evaluation of accident rate and delay costs

A study has been made to compare safety and efficiency in a number of competing European ports. However, data on nautical accidents and delay times on a sufficiently accurate level, were impossible to come by.Apparently these data are regarded as more or less classified, as they may play an important role in the analysis of port performance. It may be concluded from the foregoing that the Port of Rotterdam is not in any way afraid to disclose its performance to the market.

As no specific data were available we had to rely on the general data for nautical accidents and a number of hypothetical cases for delay times.
Related to the tonnes handled in various ports, Rotterdam has a quite favourable accident rate, as may be seen from the following table:

<table>
<thead>
<tr>
<th>Port</th>
<th>Heavy accidents per ton transshipment (1985)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotterdam</td>
<td>0.037</td>
</tr>
<tr>
<td>Antwerp</td>
<td>0.055</td>
</tr>
<tr>
<td>Hamburg</td>
<td>0.093</td>
</tr>
<tr>
<td>Singapore</td>
<td>0.107</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>0.184</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>0.255</td>
</tr>
</tbody>
</table>

To get a feeling of the position of the Port of Rotterdam as far as delay times are concerned, we considered two hypothetical cases:

- Rotterdam is situated behind locks;
- Rotterdam has tidal restrictions for vessels with a draught over 34 ft.

In the first case the total delay cost would amount to £85 mln per year, assuming a relatively favourable handling time in the locks of 1.5 hours.

In the second case about 20% of all vessels would be subject to waiting times due to tidal restrictions, resulting in the estimated total annual delay cost of about £40 mln.

The total actual delay cost of £20 mln in Rotterdam compares favourably with these figures.
3.6 System cost

As has been stated earlier, the following components can be distinguished in the nautical safety system:

- nautical infrastructure;
- nautical services.

At this moment a study is being carried out to determine which part of the cost of the infrastructure could be accounted to the nautical safety system. The picture is rather clear as far as the cost of the nautical services is concerned. Maintaining the distinction between VTS, patrol vessels, pilotage, tug service and linesmen, an inventory on the cost of nautical services resulted in the following:

<table>
<thead>
<tr>
<th>Table 4: Costs of nautical services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual cost (Mfl.)</td>
</tr>
<tr>
<td>VTS 55</td>
</tr>
<tr>
<td>Patrolling 25</td>
</tr>
<tr>
<td>Pilotage 80-100</td>
</tr>
<tr>
<td>Tug service 70-90</td>
</tr>
<tr>
<td>Linesmen 25-30</td>
</tr>
<tr>
<td>Total 255-305</td>
</tr>
</tbody>
</table>
4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary

In summing up the results from the previous paragraphs, we arrive at the following picture:

- annual damage cost $f$ 20 Mfl
- annual delay cost $f$ 15-20 Mfl
- annual system cost $f$ 225-305 Mfl

4.2 Conclusions

A number of conclusions can be drawn from this overview:

The accident cost as determined in the previous paragraphs relate to the first category of accidents mentioned in chapter 1: the "daily" accidents. Due to the availability of a safety system, no large scale accidents or catastrophies have occurred in the past decades.

Increasing the system cost cannot be justified from the point of view of decreasing damage or delay cost. Apparently the system is so sophisticated that the law of diminishing returns applies.

The only reason for increasing system cost could be found in the dependency between the different accident categories: decreasing the number of "daily" accidents could decrease the probability of occurrence of large scale accidents and catastrophies. As yet we have no reason to believe that the present probabilities are too high.

Apparently we should strive for an efficiency operation: decrease the system cost, while maintaining the present quality of the nautical services.
4.3 Future actions

In setting out the course for such an efficiency operation the Rotterdam Municipal Port Management is taking the following steps:

**Improving the Vessel Traffic System:**
The VTS manages shipping, using all resources, such as the VTS itself, the harbour patrol services, pilot services, tugboat services. The Vessel Traffic System itself must enhance the quality of the port. Quality in safety and efficiency. The VTS is a decision-supporting system, enabling the traffic coordinator to decide and advise on movements of shipping.

It has a vast information network, the Data Handling System. This is the administrative reflection of the actual performances in the port and can be seen as the real-time element of a Port Information and Management System (PIMS). A PIMS is the Port Authority’s managerial tool for making the right decision at the right time. To make past experiences readily accessible. To set strategic goals, as the past affects and limits potential alternative future scenarios.

**Introducing the Waterdepth Management System:**
The Waterdepth Management System optimizes meteorological, current and water depth information as part of the data structure of the Vessel Traffic System. The objective is to provide the VTS operator with decisive information on hydro/meteo phenomena, its predictions and the influence on the keel clearance and/or tidal window of a defined vessel, en route to and alongside her berth. So the system provides information on whether a ship can, at a given time, with a defined draught (keel clearance) and a specific velocity, proceed safely from the entrance of the harbour to a berth and vice versa, and checks the draught alongside the berth during the first tidal cycle.

Introduction of the system will result in a more efficient operation and a reduction of ship delay times.

**Carrying out studies:**
to define criteria to be applied in Nautical Quality Control within the port and, within the EEC funded Euret program, exploring the potential possibilities of a further introduction of shore-based pilotage;
Maritime simulation:
The last development to be dealt with here refers to maritime simulation as important tool in harbour design, training, research and education. Rotterdam will have a Maritime Simulation Center. Manoeuvring simulators have got a wide range of applications during the last decades. They have proved their usefulness in the following areas:

- engineering and port design evaluation;
- training of ship’s officers and pilots;
- port management support and trouble shooting.

The Rotterdam municipal Port Management has a wide experience in the use of simulators for design, training and support purposes. Different simulators have been used, ranging from simple radar simulators to the most sophisticated ones available. At this moment Rotterdam builds a Maritime Simulator Center, MarineSafety Rotterdam (MSR), comprising five manoeuvring simulators and a Vessel Traffic Simulator. The objective is to have in the Rotterdam area an assortment of skills and knowledge which in fact will be the world’s foremost Maritime Knowledge Center on port and fairway design, its interrelated logistics as well as on education and training.

In following this course Rotterdam expects to maintain the high quality standards while reducing cost.
Clean harbours by cleaner production: Reflections on Sustainable Port Operations in the Rijnmond area
L.W. Baas

Abstract

Harbours all over the world have a long tradition as focal points in distribution. In this paper, attention will be given to the symbiosis between economical and ecological aspects of harbour related activities and the societal need for Clean Living in the Rijnmond area. The Rijnmond area is the geographical area between the city of Rotterdam and the North Sea, on both sides of the river Rhine. In this area, industrial activities, related to the Rotterdam port, are executed. The industrial sector is dominated by oil refineries, chemical companies, storage and transport operations, and, though declining as an industrial sector, shipyards. The balance in the symbiosis as an important aspect of Clean Living has been challenged in the strongly growing harbour activities after 1945.

Three points of attention will be explored:
* the environmental awareness by citizens of the Rijnmond area;
* the environmental problems by harbour activities and toxic harbour sludge;
* the reduction of pollution by Cleaner Production.

Introduction

In this paper, attention will be given to the symbiosis between economical and ecological aspects of harbour related activities and the societal need for Clean Living in the Rijnmond area. The Rijnmond area is the geographical area between the city of Rotterdam and the North Sea, on both sides of the river Rhine. In this area, industrial activities, related to the Rotterdam port, are executed. The industrial sector is dominated by oil refineries, chemical companies, storage and transport operations, and, though declining as an industrial sector, shipyards. The balance in the symbiosis as an important aspect of Clean Living has been challenged in the strongly growing harbour activities after 1945. First, attention will be given to the development of environmental awareness by citizens of the Rijnmond area. Next, the environmental problems of harbour activities and the storage of toxic harbour sludge are described. Finally, the possibilities of the reduction of pollution at source by Cleaner Production will be illustrated with case studies.
2 Environmental awareness of citizens in the Rijnmond area

The Rotterdam port has brought much prosperity to the Dutch economy in the 20th century. Both the transit function of the harbour and the bulk chemical industry were major parts in economic growth. But the prosperous growth had its dark sides too. In the second half of the 1960's, citizens in parts of the Rijnmond area were bothered by the increase of environmental pollution. Many citizen's protests against air pollution started. The protest movement became the base for a breakthrough of the environmental issues on the political agenda (Boender, 1985). In 1970 the National Government declared the Rijnmond area as an "Environmental Redevelopment Area". Many Pollution Control measures were taken, among others the development of high chimneys. By doing this, the environmental problems were not solved, but merely transferred to another area. The state of the art of meeting the requirements of the environmental regulations in 1990 have been reason for the National Government to remove the declaration of the Rijnmond area as an "Environmental Redevelopment Area". This will not say, that environmental problems do not exist anymore. Today, citizens in the Rijnmond area perceive as major industrial environmental problems, industrial risks, stench and noise, air pollution, dust and soot deposits. As the environmental awareness of citizens has been mobilized by the severe pollution in the late 1960's, the sanitation works in later periods restored the trust of many citizens in the Rijnmond area, that industry can control the environmental aspects. The environmental awareness in The Netherlands in general has always been high. It has even increased in period 1988 - 1990; the percentage of Dutch citizens, involved with environmental problems, has increased from 40% in 1988 to 56% in 1990. In the Rijnmond area, environmental care is, next to health care, seen as the second most important societal issue (Province of South Holland, 1991). The Province of South-Holland is monitoring the citizen's judgements of environmental problems periodically. In relation to the involved environmental problems, the amount of impediment has increased too. The percentage of hindrance of several industrial environmental problems in the Rijnmond area in the category "of ten" are monitored in 1988 and 1990. Because "often" is a subjective qualification, the citizen's definition is asked too: 30% is saying 1 or 2 times a month, 70% are varying from once a week to each day.

<table>
<thead>
<tr>
<th>Environmental aspect</th>
<th>% hindrance in 1988</th>
<th>% hindrance in 1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial stench</td>
<td>54 - 74</td>
<td>75 - 75</td>
</tr>
<tr>
<td>Industrial dust/soot</td>
<td>58 - 51</td>
<td>72 - 68</td>
</tr>
<tr>
<td>Air pollution</td>
<td>23 - 24</td>
<td>30 - 29</td>
</tr>
<tr>
<td>Industrial risk</td>
<td>5 - 12</td>
<td>8 - 7</td>
</tr>
<tr>
<td>Industrial noise</td>
<td>24 - 29</td>
<td>29 - 31</td>
</tr>
</tbody>
</table>

The data of the Rijnmond area are 2 to 4 times as high, compared with
a reference area. The data show, that the environmental problems in the Rijnmond area need continuous attention. The trend of the data in the last three years underscores this even more.

3 Environmental problems in the Rijnmond area

The sediments of the estuary of the rivers Meuse and Rhine have raised the present land, called Holland. That estuary is now developed into a thriving part of the country. The geographical situation as entrance of one of the most important trade routes into Europe has made the port of Rotterdam since 1962 the largest transit port in the world. This expansion was possible by the construction of artificial harbours, designed through innovative approaches of Rotterdam port authorities. These harbours need continuous dredging. The Rijnmond area is one of the trigger points in the Dutch economy. To keep the actual position innovative approaches to economic development have to be sustainable. This means, that the port authorities have to cope with the environmental problems in the Rijnmond area. Three main sources of environmental pollution are detected:

a) water pollution in the river Rhine;
b) environmental problems of port activities;
c) environmental problems of local industrial area.

Additionally, the river Rhine provided the area several functions in the recent past. The sediments of the dredging were used in agriculture as well as for preparations of foundations for new housing-estates. Another function was drinking-water supplier. More than 20 million people are dependent on this function in the total river basin. Due to severe pollution of the Rhine however, the river no longer meets the requirements of these last two functions in the region of Rotterdam. In the beginning of the 1970’s the reduction of the Rhine water quality was reason for the city of Rotterdam to change the intake of drinking-water from the river Rhine to the river Meuse. A few years later the harbour sludge was found to be so contaminated with heavy metals and organic compounds that the application of this sediment for agricultural purposes was no longer safe.

As dredging is a continuing activity in order to keep the harbour open to the proper depth, Rotterdam had to find other ways of managing the sludge. The dumping of the sludge in the sea, one of the solutions, was no longer possible because of a ban by the Dutch administration. Furthermore, storage on land, another short term solution, became undesirable because the resistance of citizens and local authorities gave too much delay. Due to these developments the city of Rotterdam became obligated to store the sludge in several specially-made dumpsites. An example of this last ‘solution’ is a dumpsite made in the sea, called ‘Slufter’. This dumpsite should provide for the storage of sludge of a certain qualification up till the year 2002. However, the ‘Slufter-project’ is an undesirable solution because of both ecological and financial reasons (as a matter of fact, this “end-of-river” solution is a specific example of an “end-of-pipe” solution). The actual costs of this project are estimated to be some Dfl 200 million, a strong reason to look for more preventive ways of dealing with the pollution of the river Rhine.

In 1984 the Rotterdam-leaders have, therefore, formulated a Rhine Research Project. Based on the detection of the big polluters of the river Rhine and research into the possibilities of using civil law, a dialogue with chemical industries resulted in some covenants in 1991. In these covenants, goals were set for the reduction of certain emissions to the river Rhine in a certain timeframe. The preference of approaches to reach these goals has not been the subject in these covenants. Thus, a real opportunity was missed to implement reduction
of pollution at source, because some basic conditions for the process of Cleaner Production - goalsetting in a certain timeframe - are implicitly agreed in these covenants.

ad b)
The major environmental problems of port activities are related to the ships (used oil, maintenance) and the trans-shipment of resources and cargo. Based on Dutch environmental regulations, measures for pollution control have been taken, such as special roof constructions of storage tanks to reduce vapour emissions. For ships a harbour facility for the collection of used oil is available. There are many terminals for the trans-shipment of oil, coal, fertilizer, corn, cattlefeed and cargo in seacontainers. In the trans-shipment, still dust and noise problems occur. To promote further progress, the Rotterdam port authorities have developed a policy plan, "Clean Harbour 2000".

ad c)
The Rijnmond industrial area is rather monolithic with oil refineries, chemical companies and trans-shipment and storage facilities. The manifestating environmental problems in the 1960's and 1970's are managed by "Pollution Control" measures. In the 1980's, process integrated technologies were applied more and more. Though the big companies are developing "environmental care systems" within their plants, air and water pollution problems still need attention.

4 Reflections to Cleaner Production

In this paragraph the possibilities of Cleaner Production are described. Policies in existence are proving to be inefficient, too time consuming, and in some cases a hindrance to the reduction and prevention of pollution at source. The design and implementation of adequate policies needs much creativity and commitment to bring about the changes in practices necessary for cleaner waters in a reasonable time period. Two significant consequences of the application of the pollution prevention and waste reduction concepts are that the prevention of the production of industrial wastes increases company profits and improves the environment, simultaneously. Such an approach, in relation to water pollution, should focus upon both of the following types of emissions:

a) reduction of emissions from industrial point-sources;
b) reduction of emissions from non-point sources.

In contrast with the earlier "pollution control" approaches which manage produced pollutants, the concepts of Cleaner Production address both the technical as well as the attitudinal, motivational and other non-technical dimensions in an "anticipate and prevent" approach rather than in a "react and treat" approach (Baas et al, 1990, Huisingh and Baas, 1991). Besides that, Cleaner Production is proving to be beneficial environmentally as well as economically. Cleaner Production is an on-going process towards a minimal waste and minimal risk status for the companies. Governmental policies to promote Cleaner Production and citizen commitment to making the necessary attitudinal and behavioural changes are integral components of Cleaner Production approaches, designed to help in ensuring sustainable societies. Under Cleaner Production is meant (Baas et al, 1990, Huisingh and Baas, 1991):

CLEANER PRODUCTION, is the conceptual and procedural approach to production that demands that all phases of the life-cycle of a product or of a process should be addressed with the objective of the prevention or the minimization of short and long-term risks to humans and to the environment. A total societal commitment is required for effecting
this comprehensive approach to achieving the goal of sustainable societies.

Corporate leaders are challenged to address all aspects of the entire life-cycle of their products, including (Baas et al, 1992):

a) The evaluation of the societal relevance of a product;
b) The design of the product and the product development;
c) The selection of raw materials for the production of products;
d) The production of the product;
e) The consumption of the product;
f) The management of the product after usage.

Cleaner Production should be an ongoing process, that involves industrialists, governmental authorities, educators and citizens in helping to ensure sustainable societies.

5 Cleaner Production case illustrations

For reasons of competition, it became essential to not only start a dialogue with industries on the basis of the possible execution of legislative power, but also to find ways of stimulating companies to alter their work processes into a more environmentally friendly and economically rewarding way. After a pilot project Baas (1989), a research program based on the Pollution Prevention Principle was operationalized (Baas and Huisingh, Erasmus Centre for Environmental Studies, 1987 - 1992) in this way. Within this program, the issue is not only to indicate specific possibilities of changing production processes on the operational level, but also to find ways of implementing the philosophy of waste-reduction on the level of (strategic) industrial management. The underlying assumption is, that the attitude of people involved in production processes need to be changed in a more environmentally friendly way by innovations in the use of raw materials and substances in a more efficient way. However, this calls not only for a change in attitude with respect to the natural environment, but calls also for evaluation of production processes in a completely different way. In this respect, it is appropriate to speak in terms of the necessity for a new environmental industrial management approach. Hommes (1988) stresses the importance of periodically making environmental audits as the basis of action for industries, while Winter (1987) focuses on systematical ecological premises in every action of industrial management.

In the research program of the Erasmus Centre for Environmental Studies, the research started with a focus on industrial activities. But later also harbour related activities, like shipyards, transportation companies and chemical industries were involved. Some case studies will be presented, based on the systematic approach of a Dutch Waste Prevention manual (de Hoo et al, 1990).

In this systematic approach, the introduction of the research in each company was followed by a visit of a research team for a special outsiders look. At the same time, the appropriate activities of the company were planned. The research-project continues with the inventarization of the environmental and economic aspects of the production process. Based on these activities, a growing awareness of involvement with the other dimensions of production usually develops. After that, feasibility studies for technical, environmental and economic aspects of priority options are performed, followed by the implementation of applicable options. The first features of a permanent Cleaner Production Management System will also be discussed. The research steps in this phase are to be visualized as follows:
The impact of the implemented options need monitoring and evaluation.
The results of four case studies of Cleaner Production research will be given in the next paragraphs.

5.1 Chemical company

The company, in the experiment (Dieleman et al., 1991), is a facility in the Rijnmond area within a large multinational chemical corporation. The test facility employs approximately 300 people and produces many types of resins. The process of filtering the resins was analyzed in detail and is presented here as illustrative of the opportunities for the preventive approach within this firm.

It was found that product losses due to the filtration process were 30 tonnes of resins per year. Additionally, 400 tonnes of filtration byproduct previously were reprocessed up to product specifications, each year. The rinsing of the filters between successive resin batches created another waste stream of 38 m³ of organic solvent. Periodic cleaning of the system caused another 9 m³ of organic solvent and 108 m³ of alkaline wastewater. The wastewater was treated at a wastewater treatment facility. Other waste streams were burned.

Pollution prevention options

One promising process modification was the replacement of the old filter by a new type of filter. The new filter requires more precise attention to operating conditions, but its material efficiency is much greater. The stream of filtration 'byproduct' of 400 tonnes yearly, which previously had to be reworked up to product quality, is now totally eliminated. Furthermore, the waste stream of 30 tonnes is turned into product. Further advantages are that less solvent is necessary for rinsing between successive batches and the periodic cleaning is no longer necessary.

Environmental and financial benefits

The environmental benefits are the reduction of raw material usage and the minimization or total elimination of several waste streams. The nearly 30 tonnes less product loss resulting from the filter change, represents a savings of about DFL 80,000. Another DFL 200,000 per year will be saved on operating costs by eliminating the need for reworking 400 tonnes of byproduct each year. The incineration costs of the new type of filter medium will be only DFL 20,000 compared to DFL 80,000 for the old type. The use of organic solvents will be reduced by at least 9 m³ per year and the wastewater stream of 108 m³ is completely eliminated. The savings on the purchase and recycling of solvents are not yet fully documented, but the potential annual savings are approximately DFL 50,000.

The investment costs for the new type of filters is DFL 360,000.

In summary, all process and procedural modifications will pay for themselves in one year and will provide net increases in annual profitability of almost DFL 400,000. Air emissions and water emissions will be substantially reduced or eliminated completely. Many similar changes in other portions of the facility are currently being implemented.

5.2 Shipyard

The small shipyard maintains small and medium-sized river-vessels (Olsthoorn and Baas, 1992). The main activities are: degreasing, ship's plating treatments, painting or coating, maintenance of ship-motors and propeller-shafts. The first step in the research, an inventarization of the ecological and economical aspects of the work activities, was recently finished. Though household and chemical waste and metal wastes were already collected, this was the first time in the company, that systematic attention to environmental aspects was operationalized.
Each year 2.5 tons of chemical waste, paint wastes and empty paint containers were collected. The treatment costs were DFl 5,000; the loss of resources was DFl 5,500. In the process of ships, put into dock and after maintenance out of dock, 1,400 m3 water polluted with paint wastes, rust and increments, come into the surface water. From ship's plating conservation activities, 800 liters of organic solvents are polluted. The preliminary analysis in a brainstorm session identified many options in the categories of source reduction (alternative resources, good housekeeping, new technology) and internal reuse.

Figure 3 Prevention options in the shipyard in the different categories

<table>
<thead>
<tr>
<th>Activity</th>
<th>Resource</th>
<th>Good housekeeping</th>
<th>Technology</th>
<th>Internal reuse</th>
<th>In total</th>
</tr>
</thead>
<tbody>
<tr>
<td>In/out dock</td>
<td></td>
<td>1</td>
<td>7</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Cleaning of ship's plating</td>
<td>1</td>
<td>-</td>
<td>5</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Conserving of ship's plating</td>
<td>4</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Metal-working</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>In total</td>
<td>7</td>
<td>8</td>
<td>20</td>
<td>6</td>
<td>41</td>
</tr>
</tbody>
</table>

These options will be the base for feasibility studies.

5.3 Seacontainer maintenance company

A small company, with twelve employees active in the maintenance of seacontainers, was eager to join a pilot Cleaner Production project in the Rijnmond area (Stimular project, 1992). The company-leader, responsible for the collection of data in the inventarization, was surprised by several findings, such as:

* many data were not available;
* the purchase of paint was too expensive;
* the use of the paint was ineffective.

By doing the inventarization himself, the company-leader became sensible to look at environmental aspects from a company perspective. In this process of sensibilization two illustrations were remarkable:

a) each week eighty pairs of gloves were thrown away; only the right hand gloves were dirty. This finding led to the question, if the purchase of only right hand gloves is possible. After some time a company was found: a direct waste and cost saving!

b) the spraying of paint with an organic solvent base was not so effective: the paint container consisted of organic solvents for about 50%, which was emitted in the air; about 20% of the content of the paint container was oversprayed, 5% was a residu in the paint container, so approximately only 25% of the paint container was used.
The primary emissions from the coating procedure were approximately 200 tons of volatile organic solvents (VOC's) per year and an inaccurately quantified amount of hazardous waste paint residues. The researchers discussed the possibilities of water based paints with the paint company, but the technical and economic development was perceived as too early. Half a year later, the paint company offered a water based paint with the same quality and price as the paint with an organic solvent base. After a period of experience, all the painting is done with water based paints. So less pollution to the air (VOC's), soil and water (overspray) was achieved by process modification. Another important aspect is the business relation between companies: through the demand of water based paints, the market dynamics were stimulated. Further advantages are:

* The improvement of the worker's environment. They are not exposed to organic solvent vapours and the explosion risks are taken away;
* A very high material efficiency results in less paint waste and a better energy efficiency decreases the energy use;
* Financial benefits; the exact savings have still to be calculate.

5.4 Trans-shipment and storage company

This medium-sized company is trans-shipping and storing bulk products like phosphate ore, fertilizer, nepheline and general cargo like paper, cellulose and wood. An important environmental disturbance to the surroundings is the dust development in transport activities. The product wastes in the transport system and storage compartments are major waste streams. Each year, 270 tons of collected product wastes are sold as secondary resources and 960 tons are transported to a dump site. The costs for collection of the product wastes, transport and deposit are DFL 130,000 each year. The losses of nepheline in the several trans-shipment activities are inventorized:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Dust Emission</th>
<th>Waste (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship - ship</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Ship - shed</td>
<td>5.8</td>
<td>88</td>
</tr>
<tr>
<td>Shed - truck</td>
<td>4.8</td>
<td>73</td>
</tr>
</tbody>
</table>

Several "good housekeeping" possibilities and technology improvements are detected, such as:

* in the trans-shipment ship - ship, the height of opening the crane is a major variable in the amount of dust emission;
* the funnel, used for the loading of trucks, needs a better adjustment.

Figure 4 Prevention options in trans-shipment

<table>
<thead>
<tr>
<th>Transshipment Activity</th>
<th>Good Housekeeping</th>
<th>Technology</th>
<th>Internal Reuse</th>
<th>In Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship - ship</td>
<td>3</td>
<td>4</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>Ship - shed</td>
<td>6</td>
<td>18</td>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>Ship - truck</td>
<td>6</td>
<td>5</td>
<td>-</td>
<td>11</td>
</tr>
<tr>
<td>In total</td>
<td>15</td>
<td>27</td>
<td>2</td>
<td>44</td>
</tr>
</tbody>
</table>

The research project is now in the phase of feasibility studies.
In this paper, after the presentation of the environmental aspects and the environmental awareness of citizens in the Rijnmond area, the concepts of Cleaner Production have been illustrated by several case studies. There is a growing awareness, that treatment facilities have a function in the management of the environmental pollution, but are not able to solve all the problems. The prevention of the pollution at source is the best approach. The concepts of Cleaner Production give a promising perspective to this development, because all the phases of the life cycle of the product are addressed and integrated in business innovation.

It is clear that for the well-being of mankind a development to sustainable societies is needed. As there are many sources of pollution, it is not easy to foster integrated approaches to the reduction of pollution. Cleaner Production research is fostering this integrated economic and ecological sound approach, which is also applicable in port activities. The Cleaner Production approach will stimulate the integration of environmental aspects as part of sound port management, and will be the basic requirement for sustainable port operations.
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Acceptance of incident ships in port
R.K. Mast

Abstract: The paper briefly mentions the various bodies that are active on the international scene to promote safety of shipping. It then touches on Port State Control and its results. The various types of incident ships are mentioned, as well as the legal tools that are available to owners, underwriters and port authorities. It summarizes the parties involved in combatting the problems on the incident ships. The general sequence of countermeasures is highlighted and so is the role of the media. The conclusive remark stresses the need for a change in attitude of all parties involved in Shipping and Port Operations.

1. INTRODUCTION

It is well known to most people who are actively engaged in shipping and port operations, that safety at sea and consequently in ports is largely governed by a host of Conventions and Resolutions of the International Maritime Organization (IMO), a vital part of the United Nations (UN). Another international association that, amongst others, strives "to initiate measures designed to protect the legitimate interests and rights of Association-members within intergovernmental and other international organizations in order to improve conditions and efficiency in ports on a world wide basis" is the International Association of Ports and Harbors [1]. National Administrations implement most Conventions, Resolutions and Recommendations of the abovementioned international bodies in national laws. In this way common ground has been created for that very interesting part of the industry called "Shipping". And finally, not to be forgotten, the port authorities, with their Port By-Laws, give the finishing legal touch when ships operate in port areas and harbour basins. The sum of all the abovementioned activities should result in a safe shipping industry and a clean environment. This is not the case however. Even in recent years we still had some tragic accidents. But a disaster that really frightened the world community as a whole was the "Amoco Cadiz", that grounded on the coast of Brittany (France), causing an oil spill of 230.000 tons. This disaster was a major incentive for the Commission of the European Communi-
ties to start working on a Directive for the EC Member States concerning the enforcement, in respect of shipping using Community ports, of international standards for shipping safety and pollution prevention.

2. PORT STATE CONTROL

The Directive mentioned above found its final form in the "Memorandum of Understanding on Port State Control" (the MOU on PSC), an agreement between the maritime authorities of fourteen European countries, that took effect from the 1st July 1982. The objectives of the MOU are:

- to co-ordinate and harmonize the efforts of the maritime authorities in relation to port state control activities;
- to assist in securing the compliance of ships with international standards regarding:
  a) safety of life at sea,
  b) prevention of pollution of the marine environment,
  c) working and living conditions on board.

Fourteen European countries have accepted the MOU standards, as laid down in the so called "relevant instruments" (LOADLINE '66, SOLAS '74, PROTOCOL '78, MARPOL '73/'78, STCW '78, COLREG '72 and ILO 147), while Canada, the USA and the CIS-countries are associated as co-operating maritime authorities. The sum of it all will eventually lead to an inspection rate of around 85% of all individual ships that use ports in the region of the states that accepted the MOU.

You may have wondered what the aforementioned text has to do with the subject of incident ships, because we still have none in sight. Well, this can change quickly now, because I would like to draw your attention to the 8th Annual Report of the Secretariat of the MOU on PSC [2], covering statistically the years 1988/1990. Without Acts of God, Perils of the Sea or any other Act of a Higher Authority, the naked facts are shown of the deficiencies of every day shipping, the ships calling at our ports and the crews manning these vessels. While bearing in mind that, quote:

"care must be taken in interpreting and using the statistics ........... accidents are not necessarily caused by a frequently occurring deficiency ........"

a Port Authority can for its own purpose make some quick scans over the following devastating scene:
1. At least 15 (!) countries scored, with an average detention percentage of 4.48 for all ships involved, well over this figure with a percentage ranging from 4.59 up to and including 22.73! [2] This leads to the conclusion that exotic Morocco and St. Vincent & Grenadines for instance may well be beautiful countries to spend a holiday, but ships of these flag states have to be received in port with special interest, if not to say reluctance.

2. A combination of the annexes 4 and 5 to the Report [2] provides, after some additional calculations, the sickening impression shown in table 1:

<table>
<thead>
<tr>
<th>major categories of deficiencies</th>
<th>deficiencies in % of number of individual ships</th>
<th>in other words: one out of the number of ships - as indicated below - calling at a port has a problem with the subject mentioned against it</th>
</tr>
</thead>
<tbody>
<tr>
<td>life saving appliances</td>
<td>60</td>
<td>9 rafts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 buoys</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 life boat and/or inventory</td>
</tr>
<tr>
<td>fire fighting appliances</td>
<td>39</td>
<td>9 dampers/valves/quick closing devices/remote control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 fixed installations, detection, inert gas, personal equipment, pumps</td>
</tr>
<tr>
<td>safety in general</td>
<td>27</td>
<td>4 safety plans, WT doors, hull damage impairing seaworthiness, stability/strength</td>
</tr>
<tr>
<td>navigation</td>
<td>26</td>
<td>20 lights/shapes/sound signals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 nautical charts/publications</td>
</tr>
<tr>
<td>ships certificates</td>
<td>14</td>
<td>11 certificates for IDPF/KLS-, radio safety- and/or safety-equipment</td>
</tr>
<tr>
<td>loadlines</td>
<td>11</td>
<td>9 ventilators/air pipes/casing, freeboard marks, windows/scuttles/doors</td>
</tr>
<tr>
<td>MARPOL Annex I</td>
<td>10</td>
<td>50 oily water separator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 record book</td>
</tr>
<tr>
<td>crew</td>
<td>10</td>
<td>25 certificates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 number/composition of crew</td>
</tr>
</tbody>
</table>

Nobody would accept as a standard practice, when travelling by air, that one out of every 25 aircrafts had in the worst possible situation: faulty life rafts, malfunctioning fire extinguishing systems, a cabin door not properly locked, outdated route charts, broken windows and an uncertified pilot.
Nor is any port authority complacent about the list of deficiencies as shown in Table 1. It is obvious that ports welcome the activities of the surveyors of the PSC and see adherence to the MOU as the largest contribution to the overall safety of shipping in ports.

It is here that the author wishes to make a recommendation to the Secretariat of the PSC. Port authorities would welcome two more annexes to the Annual Report, showing the overall performance of the different Classification Bureaus or Registers, as well as statistics about Underwriters and P & I Clubs. I think that the sooner the port and shipping industry knows the performance levels of Register and Underwriters inspections against the impartial PSC surveys, the better it will be. In my opinion some improvements are urgently needed in these branches of private enterprise.

I want to conclude this chapter with a final remark. I should like to quote Dr. J. van Tiel, representing the Minister of Transport, Public Works and Water Management of the Netherlands, on the occasion of the Fourth Ministerial Conference on Port State Control in Paris, 14th March 1991 [3]. Dr. Van Tiel stated in his speech:

"It is that the human element should be paid utmost attention. . . . . . . the human element is a complex one, determined by various factors; operational matters is only one of them. Much more study remains to be done to eventually eliminate the human element as a main cause of shipping casualties."

I think Dr. Van Tiel raised a very important point there! It is not only meant for the crew on board, in my opinion. Shipowners should think twice before accepting any crew from some exotic country, just because wages are low; there is no justification for a situation as shown in Table 1. Nor is it fair to have insurance companies or the port authority pay for the accidents caused by sub-standard ships. In the meantime, the port and shipping industry should be on the alert and be prepared for the unexpected.

3. INCIDENT SHIPS CATEGORIES

If we bear in mind what has been said in Chapter 2 of this paper, we come to the following possible division:
Very often an incident ship is already in port without the harbour master knowing it. He thought that he had accepted a normal vessel, while he got stuck with a ship with a serious deficiency as mentioned in table 1. Once the ship is in port and the problem at hand, then the process of normalizing an incident is often accompanied by a lame duck situation, parties that want to downplay the seriousness of the problems, lawsuits and surveyors. From the port authorities' side the only tools directly at hand are the (Netherlands) Law and the Port By-Laws. Very often a lot of time is involved in order to achieve an acceptable technical and financial solution.

Here we encounter from the start a more dynamic situation. In most cases the problems have already started at sea, and the owners, underwriters and salvors have already been in contact with each other. There is a strong tendency to get things done as quickly as possible, but the trick is not to get carried away with too much enthusiasm. As capt. A.D. Marshall, FNI states in his article "Salvage Services in Port Authority Areas" [4]:

"The owners' representative will assess the cost of salvage, repairs and disbursements and try to decide whether there is sufficient commercial value in the vessel to pay for these" (mostly as "General Average").

"The underwriters' surveyor will simply consider whether salvage and repairs, plus any necessary disbursements such as temporary repairs and towage, can be effected within the insured value. The salvor, in addition to assessing the technical risks in refloating or rescuing the vessel, will assess the sound market value of the vessel and deduct the estimated costs of repairs. The difference between the two is normally the fund that is available to pay for the salvage operation."

A moment where the harbour master can get very upset is when the case at hand regards a vessel, poorly insured and in a bad shape, where the various parties disappear from the scene and the situation goes into limbo. In most cases however an agreement is finally reached and liability will mostly be covered in a Letter of Guarantee from the P&I Club.

I should like to conclude this chapter with a short list of incidents that in normal port operations has to be thought of beforehand:
### TABLE 2: POSSIBLE INCIDENTS PER CATEGORY SHIP

<table>
<thead>
<tr>
<th>Incident</th>
<th>Ship Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) contact</td>
<td>X</td>
</tr>
<tr>
<td>2) collision</td>
<td>X</td>
</tr>
<tr>
<td>3) grounding</td>
<td>X</td>
</tr>
<tr>
<td>4) foundering</td>
<td>X</td>
</tr>
<tr>
<td>5) drifting</td>
<td>X</td>
</tr>
<tr>
<td>6) shifting cargo</td>
<td>X X</td>
</tr>
<tr>
<td>7) cargo handling deficiency</td>
<td>X X</td>
</tr>
<tr>
<td>8) hull damage</td>
<td>X X</td>
</tr>
<tr>
<td>9) machinery damage</td>
<td>X X</td>
</tr>
<tr>
<td>10) fire</td>
<td>X X</td>
</tr>
<tr>
<td>11) explosion</td>
<td>X</td>
</tr>
<tr>
<td>12) dangerous goods deficiency</td>
<td>X X</td>
</tr>
<tr>
<td>13) personal injuries</td>
<td>X</td>
</tr>
<tr>
<td>14) spills Annex I and II</td>
<td>X X</td>
</tr>
<tr>
<td>15) miscellaneous</td>
<td>X X</td>
</tr>
</tbody>
</table>

No problem is the same. Still a basic framework in which is indicated whom to contact, which party to mobilize, has to be at hand. The objective of this framework is to minimize injury and death and the risks when the unthinkable arrives unexpectedly, mostly in after-office hours, during local holidays or weekends.

4. **LEGAL ASPECTS**

Efforts, such as
- the MOU, its relevant instruments and the PSC surveyors,
- the use of the VTS monitoring aids around port areas and their approaches.

Do not totally banish risks and accidents, as we have learned from chapters 2 and 3. It is therefore useful to look at the various international conventions which deal with the liability of the owners of vessels, under which an owner is liable for the compensation of victims for damage caused.

1. **Maritime Limitation of Liability Conventions**
   - the 1976 London Convention on Maritime Claims,
   - the 1969 and 1971 Conventions for Oil Pollution Damage,
- the draft "HNS" Convention (currently under examination of the IMO).

The satisfactory nature of these conventions is diminished by the following facts as stated in the Report of the CLPPI-Committee [5]:
"- the liability of the shipowner is established in association with a limitation of his financial scope, which, certainly, facilitates insurance coverage."

The limitation is the product of the Gross Tonnage (GRT/GT) according to the Load Line Convention and the maximum liability in SDR's/GT.

The Special Drawing Rights of the International Monetary Fund (SDR of the IMF) is i.e. a basket of currencies which follow the average erosion of the various currencies in it.

"- the amounts of these limitations .......... are greatly devalued by monetary erosions during the long delays before a convention comes into force, e.g. the 1976 Convention did not have a sufficient number of participants to enter into force, until 1986. And in certain countries the amounts of these original limitations had already eroded by 40 to 60% in terms of true purchasing power
- thus, the USA preferred to draw-up, with its Oil Pollution Act of 1990, regulations, specific to them, which stipulate very high limitation amounts and facilitate regular updating of these sums, which, in counter party, this removes all possibility of the 1984 IMO Protocol to the 1969/71 Oil Conventions coming into force."

2. Salvage and the environment

The 1989 Salvage Convention merits highlighting because of the concession that a salvor may increase his remuneration, provided he has taken measures, in addition to the normal salvage operations, to protect or limit damage to the environment (marine, coastal and port), whether by oil or other hazardous substances. The fear in port circles was, however, that the benefits of this convention would not be felt for some time because of the usually lengthy delay before the requisite number of contracting states ratify a convention.

The Council of Lloyd’s, supported by the shipping community and IAPH, has attempted to overcome this by incorporating a number of the provisions of the 1989 Salvage Convention into the Lloyd’s Open Form (LOF). Thus these provisions have been brought into
effect internationally as soon as possible, viz. upon introduction of the LOF 1990 [6], about one year after the 1989 Salvage Convention was signed (!). LOF 1990 thus provides the port accepting a disabled or incident vessel all the latitude required for organizing such acceptance, so that the risks can be minimized and correctly covered.

In the introduction we touched on the Port By-Laws. The limitation of liabilities as mentioned above supports the need for some stronger and handier instruments when tackling the incident ship of either category. In Delfzijl/Eemshaven these aspects have been covered as follows:

3. Port by-law

The port by-law does have in its definitions a description of an "average vessel", which in short runs as follows:

"average vessel - a vessel directly inflicting serious danger, damage or hindrance, or being in such a state, through the nature of her cargo or the quality of her crew, that, according to the judgement of the harbour master, this is exceeding the acceptable risk levels in the requested berth and its adjacent port areas, or impairing the use of (a portion of) the port and her fairways by its presence."

In the relevant chapter on "Safety in the port" the harbour master has been authorized to issue a prohibition to the master of an average vessel to proceed to the port. This will of course only be done if and when precautionary measures have not been taken to minimize the risks, not only in the technical, but also in the financial aspects of the case. On top of this a rather liberal instruction has been issued from the Managing Board to the harbour master. It goes without saying that the essence of this instruction stresses the point that an evenhanded approach is paramount, that all relevant parties shall be heard and that the harbour master may avail himself of expertise where necessary. The harbour master therefore has some leeway to act, but he should be constantly aware of not only the many pitfalls along the road to a succesful handling of the problem, but also of the interests that are at stake for the port and its users.

Based on International Conventions, National Law and the Port By-Law he is now in a position to
- issue a set of "Port Acceptance Conditions",
- require "Power of Attorney" from owners/charterers, (Appendix I)
- send a "Liability Message" mostly in combination with the requirement of
- a "Bank Guarantee" (Appendix II). In case the liability message is not accepted legal proceedings will be initiated including the possibility of eventual
- "Detention" of the vessel.

5. AUTHORITIES AND PARTIES INVOLVED WHEN HANDLING INCIDENT VESSELS

As soon as it is known that a meeting is convened regarding the unfortunate incident ship, then a stampede, it seems, starts for the harbour masters' office. Table 3 gives a good impression of the guests that, whether having been invited or not, scramble for his door.

<table>
<thead>
<tr>
<th>authorities:</th>
<th>subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Ministry of Shipping and Water Management, etcetera&quot;:</td>
<td>public interest</td>
</tr>
<tr>
<td>Directorate Northsea</td>
<td>VTS aspects</td>
</tr>
<tr>
<td>Government Harbour Master</td>
<td>PSC aspects</td>
</tr>
<tr>
<td>Netherlands Shipping Inspectorate</td>
<td>water quality control</td>
</tr>
<tr>
<td>Local Representative Rijkswaterstaat</td>
<td>public interest</td>
</tr>
<tr>
<td>Provincial Government</td>
<td>public interest</td>
</tr>
<tr>
<td>Municipality</td>
<td>public interest</td>
</tr>
<tr>
<td>Port Authority</td>
<td>public and port interest</td>
</tr>
<tr>
<td>(River) Police</td>
<td>official report</td>
</tr>
<tr>
<td>Fire Brigade</td>
<td>fire fighting</td>
</tr>
<tr>
<td>Inspectorate of Labour</td>
<td>safety aspects cargo handling</td>
</tr>
<tr>
<td>Dangerous Goods Corps</td>
<td>dangerous goods handling</td>
</tr>
<tr>
<td>Committee of Inspection</td>
<td>radio active substances</td>
</tr>
<tr>
<td>Red Cross/Sanitary Services/Port Health</td>
<td>medicare</td>
</tr>
<tr>
<td>Constabulary</td>
<td>immigration</td>
</tr>
<tr>
<td>Customs</td>
<td>im/export duties</td>
</tr>
<tr>
<td>Experts (barristers/technicians)</td>
<td></td>
</tr>
</tbody>
</table>

(continued on the next page)
The trick here is to admit participants only then to the meeting after the business has been stated and the name, firm, telephone number and signature have been entered in a list. In order to keep the meeting manageable, only one representative of each party shall in principle be accepted and very often some people have to be refused admittance. The result from this approach is usually a fruitful meeting with clear, concise agreements on a variety of subjects. The larger the group that is admitted, the greater the chance that the meeting will end in a bear garden.

6. SEQUENCE OF OPERATIONS

From a recent inquiry among several Dutch port authorities it appears that in general the following sequence of activities is adhered to before an incident ship is accepted in the port or one of the fairways leading to it:

- technical inspection
  This inspection is being held outside the port, mostly at sea or in the roads. On behalf of the harbour master, safety experts board the incident vessel. They act in close co-operation with the Government, the State Harbour Master and Shipping Inspectorate and occasionally with a salvage company participant.

| TABLE 3: AUTHORITIES AND PARTIES INVOLVED WHEN HANDLING INCIDENT VESSELS |
|-----------------|-----------------|
| **parties**     | **subject**     |
| Classification Bureau | class certificate |
| Underwriters | hull insurance |
| Bailiff | transport insur. |
| Shippers' agent | interests various parties |
| Towing company | owners/charterers interests |
| Salvor | port towing |
| Linesmen | salvage |
| Pilot Service | (un)mooring and/or crew assistance |
| Shipyard | nautical advisor |
| Stevedore/Terminal Representative | repair facilities |
| Port Reception Facilities | cargo handling |
| Specialized Firms | MARPOL 1, II & V |
| Experts (barristers/technicians) | the case at hand |
- **meeting in the Harbour Master's Office**
  All relevant parties meet. The harbour master chairs the meeting. All aspects of the problem at hand will get attention, such as cargo particulars, ships' particulars, salvage aspects, financial consequences, etc. etc.
  This meeting leads to

- **Port Acceptance Conditions**
  All facts, including the results of the inspection, will be translated into a message (letter, fax, telex) with Port Acceptance Conditions. This message will be sent to the owner or his representative and his/their formal response will be awaited.

- **Salvage Agreement**
  Depending on the seriousness of the incident, a Salvage Agreement (LOF 1990 !) should be signed and/or accepted.

- **acceptance of other third parties**
  Third parties are for example the factory or installation the vessel is bound for, stevedores handling the cargo(es), port repair or dry-dock companies. The harbour master has to make certain that the participants will accept the incident vessel in their berth.

- **power of attorney**
  The power of attorney enables the harbour master to take any necessary precautionary measure against the incident vessel to make certain that the safety within the port boundaries will not be impaired (Appendix I).

- **bank guarantee**
  A bank guarantee is demanded from the owners by the harbour master to safeguard the port against claims or costs (keeping in mind the possibility of wrecking, sinking or pollution). The amount depends on the vessels' state and can be raised easily as a result of the inspection (Appendix II).

- **liability**
  In case of any occurrence of incident vessels already in port, the owners usually are held responsible for the consequences/damage/costs by sending them a liability message. It may include the demand for a bank guarantee.
If this demand is not met, there is the possibility of legal action including detention of the vessel.

When all the necessary precautionary steps have been taken, the ship will almost always enter the port and operations will start to get things back to normal. The point to stress here is to take care of a good and careful follow-up, to keep good communications with all parties involved and have a daily meeting where relevant parties shall report. Only then incident vessel handling can be brought safely to an end. The results will be most rewarding and a contribution to the interests of all parties concerned.

7. THE MEDIA

Some remarks have to be made about reporters of newspapers, radio and television. They have a job to do like everybody else. If insufficient attention is paid to their needs, then a severe setback can develop for the total operation. In nautical terms "a press of sail has to be carried" to keep reporters regularly informed about the operations at hand. Ill-informed reporters try their luck on the scene and very often hamper operations. The author furthermore has a very strong opinion on who should perform this task, viz. the Managing Director. In this way the harbour master can concentrate on the technical aspects of the problem, while the Managing Board, the Municipality and the media are being informed through the Managing Director. It is suggested to keep the information concise, clear, to the point and to operate with maximum credibility. Admit it if a prompt answer cannot be given, but come back on the subject at the next press conference. Remember that any mistake in giving correct information in general will be severely punished later.

8. CONCLUSIVE REMARK

The aim of the paper is to stimulate discussions and a better understanding of the problems and aspects for all parties concerned when handling incident ships. It is my most sincere wish that this paper, and the discussion during the Conference, will be beneficial for our common ship "PLANET EARTH" and the crew that has signed the Articles.
9. REFERENCES

"IAPH Constitution and By-Laws", Tokyo, IAPH


"Report of the Committee on Legal Protection of Port Interests (CLPPI)", Tokyo, IAPH

"Lloyd's Standard Form of Salvage Agreement", London, Lloyd's
APPENDIX

EXAMPLE "POWER OF ATTORNEY"

RE.: (name of vessel)  place/date

1. Owners and Time Charterers accept the port acceptance conditions set by (name Port Authority) for their consent on the entry of the vessel into the port of (name port), as described in the message (letter, fax, telex), dated (date), from the Port Authority to (name Owners/ Charterers).

2. Owners and/or Time Charterers herewith authorize irrevocably the (name Port authority), in case abovementioned vessel and/or cargo and/or balances of cargo in the opinion of the Harbour Master of (name Port Authority) endangers persons and/or properties of third parties to perform or have performed for their account and risk all that is necessary to decrease the danger as much as possible and whatever may be in the interests of public order, public health and matters of public responsibility, such as to give first aid, discharge, make gasfree, clean, shift and do the necessary repairs, if any.

3. Owners and Time Charterers, within the limits of the rules of Limitation of the 1976 Convention and corresponding national legislations, agree to hold harmless the (name Port Authority) from any claims by third parties against the (name Port Authority) for personal injury or death or for damage to goods arising out of the consent given by the (name Port Authority) to the entry of the vessel and/or actions taken by or upon instructions of the (name Port Authority).

4. Owners and Time Charterers undertake to pay all expenses and costs incurred by the (name Port Authority) with regard to the handling of the vessel and her cargo.

5. This undertaking is subject to the Dutch Law with acceptance of (location of Court, to be chosen by the Port Authority) jurisdiction.

SIGNED ON BEHALF OF
(OWNERS)

SIGNED ON BEHALF OF
(CHARTERERS)
APPENDIX II

EXAMPLE "BANK GUARANTEE"

(place/date)

We, the undersigned: (name Bank)

waiving and renouncing the benefits of eviction and of division of debt as well as of all other benefits and exceptions conferred on guarantors by Netherlands law, including the right to invoke the provisions of articles 6:154 of the Netherlands Civil Code, hereby declare to bind ourselves jointly and severally as surety and co-principal debtor to and in favour of (name Port Authority), hereinafter to be referred to as "the creditor", by way of security for the true and proper discharge by (name owners) and (name charterers), respectively owners and time charterers of the m/v (name vessel), hereinafter to be referred to as "the principal debtor", or whatever the principal debtor may be found to be indebted to the creditor by virtue of a judgement (which is not subject to appeal), rendered against the principal debtor - or jointly against the principal debtor and the undersigned guarantor - by a Dutch court of law, having jurisdiction in the matter hereinafter mentioned, or by virtue of a valid arbitration award or by virtue of an amicable settlement between the parties, in respect of the principal amount, interest and costs of suit relating to the port acceptance conditions for the vessel mentioned above, which are laid down in the message (letter, fax, telex) from the creditor to the principal debtor on (date).

This guarantee is hereby given without any prejudice whatever to the question of liability or to the amount involved or to any other matter in issue (including any question as to statutory limitation of liability) and for a maximum amount of Dfl. (to be filled in) (Dutch guilders in words).

This guarantee is given for the purpose of the prevention of an attachment in respect of the (name vessel).

This guarantee shall expire unless within 24 months from the date of signing thereof legal proceedings have been instituted with relation to the aforesaid issue in a court of law having jurisdiction in the matter, as referred to above, or a deed of compromise has been signed or an appointment of one or more arbitrators has been notified or requested or proposed in terms of an arbitration clause, or an amicable settlement has been concluded between the parties.

SIGNED ON BEHALF OF
(BANK)
Abstract

Dutch ports are planning to improve their services by being safer, cleaner and offering better value for money than their competitors.

A vital element in this strategy is port quality control, which depends as much on government as on the officials in the port itself.

The possibilities opened up by information technology could mean great improvements in port quality control, making it much faster and more efficient. This is illustrated with a number of examples of projects dealing mainly with safety and environmental issues.

In the future, we can envisage even more new services we might offer using information technology. Vessel Traffic Services (VTS) are an important example. Setting up VTS systems is more a matter of cooperation and organisation than of funding, and ports that opt for VTS early are likely to enjoy a competitive advantage.

The magic word - quality

For at least the last three decades the world’s largest port has been a Dutch port. But size is no guarantee of
continuing success. In common with other Dutch ports, therefore, Rotterdam has also joined the search for excellence.

There is a lot to be said for quantity, but in the end it is quality which says most about a port’s competitive position. So what makes a port a quality port?

My unhesitating answer is:
- a safe port
- and a clean port
- which offers good service
- at reasonable cost

If I were a shipowner, such a port would be my preferred port of call.

A wide range of authorities, services and companies contribute to the quality of a port. Think, for example, of the tugmen; the pilot service; the mooring crews; the cargo handling, warehousing and forwarding agents; the engineering firms; the port authority; customs; and central government. And of course the shipping industry plays a major role. The ships themselves can determine whether a port has a reputation for cleanliness and safety, and the quality of service offered.

Port quality control - why bother?

In the Netherlands, ultimate responsibility for the safe and efficient management of vessel traffic routes lies with central government. This responsibility derives from the international conventions to which the Netherlands is a party, and is established in national legislation. The Netherlands has a long coastline with several significant ports. More than half of all shipping plying the North Sea off the Dutch coast is bound for a Dutch port.

Even the other 50 per cent of North Sea shipping sailing to and from other European ports comes under Dutch responsibility when it is off the Dutch coast. Authority is mainly exercised to prevent accidents, but extends of course to emergency services, and search and
rescue. As a maritime country with major ports, the Netherlands has every interest in proper safety and environmental regulations for ships and shipping.

An additional aspect is the protection of merchant shipping worldwide - and hence the Dutch merchant fleet - from unfair competition. Slapdash shipowners should not be able to derive any competitive advantage from their failure to invest in safety and environmental protection.

International regulations are laid down by the International Maritime Organisation (IMO) and the Central Commission for the Navigation of the Rhine. The Netherlands, of course, is a member of both. So the Netherlands promotes its interests in the international fora, in its capacities as a flag state, a coastal state and a port state.

Merchant shipping is international, and the international safety and environmental regulations apply in principle to any ship which sails into a Dutch port, irrespective of the flag it is flying. The Netherlands government believes it has a duty to supervise compliance with the international rules. To perform this function, there are various bodies that enforce these rules, such as Port State Control and the Coastguard. The government also helps to set the context for the safety and efficiency of ships and shipping through its national legislation, by funding research and development, by offering incentives for new environmental technologies, and by providing the public with information.

Of course, the ports themselves have a strong interest in safe, environmentally sound and efficient shipping. Within harbour limits, the port authorities are indeed themselves responsible for these matters. So the interests of port authority and government coincide here to a large extent. Both are aiming for the same goals - no undue delays (preferably none at all) and service at reasonable cost.
International competition is so intense that only small differences in service or price are needed for a port to lose customers. With new logistical concepts, such as Just-in-Time and Door-to-Door, we need to be even more punctual and reliable.

Port authorities and government have several instruments for exercising port quality control. The most important of these are VTS for shipping, and Port State Control for ships.

Port State Control - PSC

International conventions explicitly permit the inspection of foreign ships. Inspections take place in port, since it is much more difficult to inspect ships on the open sea, and once moored a ship is under the jurisdiction of the port country. So, foreign ships can be prevented from sailing from Dutch ports if, say, they need urgent repairs to make them safe. This would happen if the Netherlands Shipping Inspectorate found serious deficiencies or breaches of the regulations.

The signatories to the port state control memorandum and their port authorities have a European organisation to coordinate their work. Here inspection procedures are agreed and information exchanged.

When Port State Control of foreign vessels was introduced ten years ago not all port authorities were happy with this new form of international cooperation. Many feared that it would make their ports less attractive, or that differences in enforcement policy between the contracting states would give some European ports an unfair competitive advantage.

Happily, this initial reluctance has since disappeared. Port State Control has not developed into the witch hunt predicted, and the results speak for themselves. If anything, the need for Port State Control has become even greater. Today, Port State Control focuses increasingly on environmental policing, through inspections of ships’ equipment and operational checks to ensure that it is being used properly.
Port State Control has been so successful that it even has a following outside Europe. One reason for this is that other regions have often found their ships barred from European routes because they do not come up to standard.

The key words in this success story are unity of purpose and cooperation, both between countries and between port authorities. Without them, unfair competition could creep in at two levels: shipowners who ignored safety would go unchallenged, and slapdash ports would become their havens. There would, of course, still be ports which shunned the cowboys.

Now, if harmonisation and cooperation contribute to the success of Port State Control, they are also essential prerequisites for any forms of port quality control.

Vessel Traffic Services (VTS)

Shipping traffic from and to Dutch ports can be dense. This is one reason why VTS systems have been developed to further the safe and efficient management of shipping traffic. The VTS-systems that have been developed for the Rotterdam Waterway and the River Scheldt are highly sophisticated.

The heart of such a VTS system is its data processing system. All kinds of information, relevant for vessel traffic management (ship’s positions, tides, cargoes etc.), is collected, processed, stored, or disseminated within or by VTS. As such, VTS has developed from what was seen as an "aid to navigation" into a basic instrument that, next to providing services to shipping, also improves the quality and effectiveness of other services concerned with safety, efficiency and protection of the environment.
PSC, VTS and IT - a new dimension

A great deal has changed since PSC and VTS were first devised. More dangerous substances are now carried. The environment has become more important. New logistics concepts have grown up - Just-in-Time and Door-to-Door. There is more international cooperation, particularly at European level. The world is literally getting smaller.

These developments create new problems for shipping inspectorates:

- inspections are more complex because more dangerous substances are carried;

- but, because of the demands of Just-in-Time and Door-to-Door, inspections must take less time, preferably without delaying the client;

- inspection reports have to be sent to other port authorities in other countries;

- and all this must cost no more than before.

There seems only one way to meet this challenge - with the help of information technology. Information technology is developing almost faster than the demands we make of it. New advances mean that we are able to collect, process and disseminate ever more data in shorter and shorter times. We can do much more, then, with exactly the same amount of information that we had before. Networking, data selection and automatic updating enable us to carry out inspections much more efficiently. The opportunities opened up by information technology are enormous.

The tools for port quality control - PSC and VTS - will have to be refined and improved in the future with the help of information technology and telematics. At the same time, we can expect to see many more applications geared to improving port services, such as automatic documentation and bills of lading.
Trends in the quality of port quality control

We firmly believe that by using information, information technology and telematics wisely, we can refine our existing quality control tools and produce a coherent package for port quality control. The Netherlands has therefore launched a number of port quality initiatives:

1. Selecting ships for PSC inspection
Let us go back to Port State Control. Every day, the shipping inspector has to decide which vessels to visit. To do this, he or she must be able to check the list of ships arriving against inspection reports from earlier ports of call. Has a ship recently been declared unfit at another port? Is there any suspicion of an illegal oil discharge?

From the outset, Port State Control has been Europe-wide. But few of the ports concerned have facilities for exchanging information on-line, although a suitable network would only take a few years to set up. An inspector would then have better information to decide which ships to visit. This is one area where good information exchange and selection would lead to a more effective and efficient Port State Control operation. The results would be an efficiency gain on the part of shipping inspectorates, and a reduction in needless delays and frustration for ships.

2. Broadening VTS objectives
Over the years, VTS has developed to a service that plays a central role in vessel traffic management. Within port, VTS may be used to coordinate traffic-related services, such as pilotage and tugboat-services. However, VTS may also coordinate in case of calamities and search and rescue operations. This supporting role of VTS towards "allied activities" is internationally acknowledged in the International Maritime Organization's "Guidelines for VTS" in 1985. To make full use of the coordinating potential of VTS it is essential to canalize the information flows through the VTS. Over the years, a great number of VTS systems has been developed. At present, most North West-European sea-ports operate such systems. This offers new opportunities for cooperation between
different VTS-centres. An exchange of information between those VTS-centres can reduce a ship’s reporting requirements considerably, and it may speed up procedures related to cargo handling, customs and immigration as well. Information thus received may also be used to anticipate on entry clearances and to plan arrivals. As such, cooperation between VTS centres may enhance the efficiency of traffic flows.

3. Promoting MARPOL in ports: PMP

On arrival in port a ship is asked to report the quantity of slops in its tanks. The harbourmaster tells the captain where he can empty his tanks and the fee that will be charged for the use of a shore reception facility. If the ship then sails without discharging its slops while its tanks were reasonably full, it could be planning to discharge illegally at sea.

In these circumstances, a ship could be earmarked in the port’s database with a note of its next port of call. Inspectors at the next port would look especially for empty tanks, as proof that the draincocks had been opened at sea.

This project is a Dutch initiative which is already being tested in Rotterdam. This kind of port quality control encourages the use of shore reception facilities in port, and enforces the environmental regulations more effectively. Slop tank data should be included in the information exchanged by European port authorities. So far, the response from other European countries has been positive.

4. Bonus malus

Information can be used as easily to reward good behaviour as to punish bad. You heard a lot about the green award in the last lecture. That is a good example of the bonus system. It is quite conceivable that the bonus malus system will be applied more widely in the future. But such a system is only feasible if enough information can be processed and exchanged by the authorities involved. And that is only possible if modern information technology is used. For the time being, the green award remains a Dutch – and specifically a Rotterdam – initiative. It comes into force in 1993.
5. Reporting, Information and Monitoring (RIM) system

The carriage of dangerous substances by sea is on the increase in Western Europe. The chances of an accident are increasing too, with risks for the environment and for crews.

Technical standards covering the transport of dangerous goods are getting tougher all the time. But when an accident happens it is vital to know what is - or was - in a ship's hold. People involved in search and rescue or salvage operations need this information urgently. It might determine what action they need to take. An information network linking European ports could be the answer.

A ship carrying dangerous substances reports to the authorities in its next port-of-call 24 hours before it docks. Such information is required anyway for normal port planning purposes. If anything were to happen to the ship, there would then be a good chance that it had already reported its position and cargo to a European port. Its last known position could then be calculated by dead reckoning. In an emergency, these data would have to be directly accessible to, say, the coastguard coordinating search and rescue, the salvor, or others involved in the rescue.

The RIM system could therefore provide the information needed to decide on appropriate remedial action. All the North Sea states have agreed that such a system would be extremely useful. The Netherlands is pressing for an international RIM system, and is setting one up at national level.

European Waters Traffic Information System (EWTIS)

To achieve all this information exchange between port authorities and coastguard stations, we need a four-lane highway - in a communications sense - with everybody obeying the same rules. This means using harmonised and standardised messages (EDI) as much as possible. It also means using information which is already available as far as possible. The EC has already invested in this. The EWTIS Project (European Waters Traffic Information System) which started this year should produce a pilot network linking ports in participating countries by the end of 1993.
Initially, the network could be used to exchange information on ships sailing with full slop tanks, for search and rescue, salvage or disaster response, and to facilitate messages relating to Port State Control. In the long run, we hope the project will be expanded to cover much more information. The Netherlands is an active player in EWTIS, contributing both manpower and money.

Cooperation through information

The great advances made in information technology are helping port authorities and government to address the ever more complex issues of port quality control.

The beauty of IT is that it lets you handle the same amount of data you had before in a much more efficient way. You are not asking people to collect more data. All you have to do, as port authorities and governments, is to work together within well-defined objectives. And of course, this implies treating any commercially sensitive information with due respect.

But the benefits are enormous. After all, an efficient, safe, and environmentally responsible shipping industry has got to be in the best interests of both port authorities and governments. And the customer gets a better service for roughly the same price. This will inevitably bring in more customers - so there is a competitive advantage, too.

Information technology and rapid advances in telematics are forcing us to move into a higher gear than we envisaged a few years ago. We must grasp this opportunity and turn our paper ideas into the reality of port quality control as soon as we can. That is why the port authorities and the government sometimes encourage each other to embrace new applications, even before their full significance has been realised.

No doubt Dutch ports will have to face fresh challenges in the future. But as long as we regard these challenges as opportunities, we will remain masters of our own destiny.
The vessel traffic service

H.W. Daniëls

THE VESSEL TRAFFIC SERVICE

General description

Rotterdam started a vessel traffic service in 1956 with a chain of 8 radars. This radarchain was replaced in 1987 by the new Vessel Traffic Management System. After several years of preparation, construction started in 1982. The system is just completed (May 1992).

The area covered stretches from 60 kilometres off-shore to 40 kilometres inland. This area is divided into three regions, each with its own traffic center. Region Hook of Holland covers the seaward approaches, Europoort and part of the Waterway. Region Botlek consists of the Botlek area and surroundings, part of the Oude Maas River and the Hartelkanaal. Region City covers the remaining part up to some kilometres upstream of the Brienenoordbridge. Traffic center Botlek has a subsidiary traffic center Hartel. The subsidiary traffic center Maasboulevard is part of the traffic center City.

Each region is subdivided into sectors, 5 in Hook of Holland, 3 in Botlek and 4 in City, giving a total of 12 sectors. Each sector is manned by a radar-operator, who is in direct contact with the shipping in his sector via VHF-radio.

The Harbour Co-ordination Center (HCC) co-ordinates the operations of the 5 traffic centers. The HCC comprises Central Traffic Control, Planning and Dangerous Goods.

Central Traffic Control assigns berths to ships, makes arrangements for admission of ships in co-operation with agents and pilots - especially for special transports and tide-bound vessels - and functions as an emergency center for incidents or calamities in close co-operation with the patrol-vessels, the firebrigade and the police.
Planning plans the admission of vessels, plans and orders services for ships entering, leaving or shifting (pilot, tugs, linesmen). Planning also updates the berth overview and gives information to third parties.

Dangerous Goods supervises the transshipment of dangerous goods with a team of Dangerous Goods Inspectors.

The (private) pilot organization has an operational room next door to the HCC, making use of the equipment of the VTMS. In the near future there will be a Nautical Service Center in which the port authority, the pilot, the linesmen and the tugboat organizations are working together.

**Procedures**

A ship’s visit is notified at least 24 hours in advance by the agent, who sends a Notice to the Harbourmaster to Central Traffic Control, comprising the ship’s particulars, the berth and the services required (pilot, tugs, linesmen). If applicable, a Notice of Dangerous Goods is also sent by the agent to Dangerous Goods.

At least 6 hours before arrival the captain sends an ETA Pilot station via the coastal radio station to the HCC.

![Figure 2 APPROACH TO ROTTERDAM](image)

When within VHF range, the captain contacts the sector Maas Approach in Traffic Center Hook with an updated ETA and other particulars. The ship is then identified on the radar screen by means of the Radio Direction Finders and is subsequently labelled by the radar-operator.

The pilot boards the vessel in sector Pilot Maas and he will give an ETA for the entrance to the harbour basin where the ship is to berth. This time is important for the tugboat- and linesmen organizations, and also for customs and immigration.

The normal procedure of the radar-operators is to give information to the captain or the pilot on the traffic situation, the ship’s position if necessary, the intentions of other vessels and other relevant information. In principle the captain remains responsible for navigating his vessel, making use of the information received.
There is also an advisory mode. When the pilot service is suspended due to seastate, it is possible for some categories of vessels to accept remote pilotage. Apart from the sector Pilot Maas, which is continuously manned by a pilot, sector Maas Entrance will also be manned by a pilot. From the radarscreen the pilot advises the captain on course and speed up to a point where another pilot can board the vessel.

Of course it is also possible to give binding orders to vessels, but only under special circumstances, on behalf of the port authority.

Technical description

From a technical viewpoint the VTMS consists of radars, automatic trackers, radio direction finders, television, hydro-meteo sensors, communication equipment, voice logging recorders, video recorders, system control monitors, data processors and consoles with radardisplays and visual display units, all accommodated in specially designed buildings.

Radar

The main sensor is a network of 26 radars. Sea coverage ranges all the way to the entrance of the Eurochannel, on account of a radar on the Goeree Light Platform. Apart from the main fairway, also Europoort and the central channels of the Beerkanaal, Botlek, Eemhaven and Waalhaven are under radar coverage. Twenty-three out of the twenty-six radars are placed at unmanned locations.

The radars are working in the 9 GHz band (3 cm). They have a peak power of 40 kW. The slotted wave guide antennae rotate at 20 r.p.m.

For the two long range radars for the seaward approaches the beamwidth is 0,25 degree, with a pulse length of 200 ns and a (staggered) PRF of 2000 Hz.

The remaining short range radars have a beamwidth of 0,4 degree, pulse length 50 ns and a PRF of 2300 Hz.

All radars are equipped with a Constant False Alarm Circuit (CFAC) - an automatic threshold for raw-video - and an Interference Suppression Unit for other 3 cm radars in the vicinity.

An expander makes the 50 ns radars suitable to transmit the raw-radar signal, via a 5 MHz bandwidth micro-wave link, to the traffic centers, making use of the dead time between pulses.

Non-relevant areas (land masses) are masked to create a clear raw-video picture of the water area only, with a narrow band of the water-land boundary. Three radars have a double transmitter/receiver configuration, because of their location (difficult to access). The remaining radars have single configurations. There is enough overlap between the radars to put a radar out of operation, for instance for maintenance, during a short period.

All radar stations are equipped with an emergency power supply unit, just as all traffic centers and the HCC.
Because the power of the 50 ns radars, working on relative short distances, is considered too high, causing many reflections and big echo's, measures have been taken to install a RF-STC and CFAC-STC in the receiver-circuit to tackle these problems. Trials with these STC's showed a remarkable improvement in raw-radar presentation.

Automatic tracking

Each radar has its own tracking system. At the radar-site the Video-Extractor masks non-relevant areas from the received raw video and digitizes this video. The digitized video is processed in the Plot Processor, also at the radar-site, which detects targets in the video. For each target the Plot Processor determines position, dimensions, orientation and echostrength. These target characteristics are transferred via telephone line to the Track Processor in the traffic center as target reports. The Track Processor executes two main functions:
- automatic tracking by correlation of incoming target reports to existing tracks;
- automatic initiation of new tracks, based upon non-correlated target reports.

All local tracks from the radars in a region come together in the Multi Radar Track Processor (MRTP). The MRTP compares the tracks received and makes a selection of the tracks, from then on called system tracks. Because the main fairway and the most important harbour basins have double radar coverage (a ship will be detected by at least two radars), the MRTP can reduce ghost echoes to a large extent: a ghost echo (or reflection) will not be detected by two radars at the same time in the same position. Because of the double coverage shielding effects can also be eliminated. The MRTP "knows" that an area behind a big vessel is an obscuring area for one radar, and will accept that only one track is available from another radar.

Within the MRTP the available data of a vessel from the Data Handling System (name, dimensions, category of vessel, destination etc) will be coupled to a track by the operator when identifying a vessel on his screen.

The system tracks are transferred to the radarscreens. Track information on the screen stems from all relevant radars in the region, giving a "total" traffic picture.

To ensure double radar coverage for the MRTP's in the boundary-area between two regions, and also to maintain ships' identities when crossing this boundary, the MRTP's exchange track information with each other from the radars near this boundary.

All system tracks are stored in the MRTP for 1 1/2 hour continuously and are then removed, unless the operator presses his "incident-key". Track information from the last 1 1/2 hour and the track information for the coming 1 1/2 hour is then stored and can be replayed afterwards, either for training or for legal purposes.

Every minute the MRTP sends the system-tracks to the Data Handling System, where they are processed to produce lists of vessels sailing in a certain area and to calculate expected times of crossing certain boundaries, for instance the next sector.
The capacity of the tracking system is 120 local tracks per radar and 400 system tracks for the MRTP. When the maximum amount of tracks is surpassed, the MRTP will start to remove the smallest tracks. This can, for instance, happen in areas with lots of buoys (a buoy also presents a track). To overcome this problem a "window" is put around each buoy. Within this window no tracks are processed. The buoy will be visible on the radarscreen as part of the map, which is also processed by the MRTP.

Each radarscreen can handle a maximum of 75 tracks with a refresh rate of 30 Hz. More tracks to display will lower the refresh rate down to 20 Hz at 150 tracks.

Problems

A sound tracking system within a port environment is difficult to achieve, because of the many reflections that occur, the obscuring effects, ships passing each other very closely, ships passing radarscanners at short distances, high seastate etc.

Ghost echoes caused by reflections are quite well tackled by the MRTP in areas with double radar coverage. The MRTP can also handle obscuring effects quite properly. Merging and splitting of targets can not always be prevented. The radar-operator can "tell" the MRTP to combine two tracks when splitting occurs or to split a track when merging occurs. The MRTP will try, but it is not always successful.

Another difficulty is the smearing out of targets due to internal reflections in the vessel (hatches for instance), resulting in wrong vessel dimensions, wrong position and wrong orientation. A solution could be to get the dimensions from the Data Handling System, to do "flank detection" for the proper position and to couple the measured orientation to the calculated ground-course (when there is not too much cross-current).

The problem of losing tracks, especially with high sea state, is difficult to tackle. A threshold that is too high will cause small vessels to disappear from the screen, a threshold that is too low will cause many false targets, overflow of the tracking system etc. Maybe correlation techniques are the answer to this problem.

Initiation of a new track takes about 30 seconds. The tracker needs that time to gain enough confidence in a new track. But in 30 seconds a vessel, coming into the radar covered area to cross the main fairway, can travel quite a distance, and will show up as a track when it is almost in the middle of the fairway. Shortening the time of 30 seconds will cause more false targets. A solution - apart from transponders - is not yet available.

Of great assistance in all these difficulties is that the Rotterdam VTS presents the tracker information together with the raw-video from one selected radar on the same screen. A radar-operator can correlate, detect merging and splitting, see a raw-video target appearing etc.

Radio Direction Finders

Along the coast three Radio Direction Finders are installed at distances of appr. 35 km. Ships reporting by VHF-radio to the Hook of Holland traffic center will be picked up automatically. The bearing information is sent by
telephone lines to the traffic center and processed to show bearing lines on
the radarscreen. The echo of the ship will be close to the point where the
lines intersect, which makes it possible to identify echoes on the screen.
The lines are displayed for a period of 3 seconds.

Sometimes the system is also used to detect targets in the clutter, when the
radar is not able to produce tracks of, for instance, small vessels.

The RDF-antenna consists of 32 dipoles, mounted on a 6 m diameter circle.
The accuracy is better than one degree. The distance from which signals are
picked up depends of course on the height of the RDF-antenna and the height
of the ships antenna. For normal seagoing vessels the RDF-range is about
equal to the radar-range.

Each RDF-station has three receivers covering the three radar-channels used
in the seaward approaches.

The southern most RDF-station is also used by the Scheld-river radarchain.

Radar screens

The 50 cm diameter radarscreens show the raw-video picture of one selectable
radar, vessel symbols, labels, RDF-bearing lines, the map, tables with
information and a command-menu to operate the screen. Speed vectors,
calculated by the tracking system, can be attached to vessel symbols. The
tracking system can also calculate distances between vessels or between a
vessel and a fixed point, updated every 3 seconds. In addition the closest
point of approach (CPA) between two vessels can be determined. Approximately
half the number of screens are equipped with dual fosfor layers, permitting a
good picture of both raw radar video (requiring a long afterglow) and
synthetic video, which requires a short afterglow.

Figure 3 THE SYSTEM SET-UP
Television

From the very beginning the Rotterdam radar-operators have stressed the importance of overlooking the traffic situation visually in addition to the radarpicture. Although there are five traffic centers, situated near areas with difficult traffic patterns, other areas still remain where a visual overview is found to be necessary. Near these areas television cameras are installed. The cameras have fixed focused lenses. On some locations cameras with different focal distances are mounted on top of each other. As a result, one picture is as it were a blow-up of the other. The television signals are transmitted to the traffic centers via micro-wave links.

Micro-wave links

The broad-band raw-radar and television signals are transmitted via 5 MHz bandwidth micro-wave links, working in the 10 and 40 GHz band. The radars covering the sea-side make use of 10 GHz links. The 40 GHz links are a fine-weather solution. Difficulties arise during snow and heavy rainshowers, in situations that one needs the information more than during nice weather. Plans are being worked out to install 23 GHz links instead of 40 GHz.

Another possibility to transmit the raw-radar video, apart of course from the very expensive coaxial cables or fibre-optics, is to reduce the bandwidth by removing redundant information and only transmit changes in the information from scan to scan. This requires digital scan conversion and other displays being used now in the Rotterdam VTS. These systems are already available, using normal telephone lines.

Radio-communication

VHF-maritime radio is used for communicating with ships. Each of the 12 radar-sectors has a separate channel. All ships are obliged to guard these channels while sailing the VTS-area. Switch-over positions are indicated ashore by illuminated signs.

The regional traffic controllers in the traffic centers guard channel 13 for administrative purposes like notices of planned departure.

Likewise Central Traffic Control in the Harbour Co-ordination Center guards channel 11, the Port Operations Channel.

Channel 14 is available for notices of planned disposal of waste at port reception facilities.

The Hook of Holland traffic center guards the international calling and emergency channel 16. Also available there is channel 9 for communication with helicopters operating in the seaward area, for instance for transport of pilots to deep-draught vessels.

For internal use several separate VHF-radio nets are available:

- Central Traffic Control with patrolvessels
- Regional Traffic Control and deputy-harbourmasters with patrolvessels
- Dangerous Goods with the Dangerous Goods inspectors
- Pilot organization with the pilots
- Pilot organization with the pilotcutters and pilottenders
- Pilot with the tugs and linesmen
- Emergency
Patrol vessels, pilots and inspectors can be contacted with selective call.

To prevent as much as possible interference with the same VHF-channels used in other ports, the antenna-pattern is designed in an East-West direction.

**Integrated communication system**

All voice communication via VHF-maritime radio, internal VHF-radio nets and telephone is directed on shore-based workpositions from one key-board which has been incorporated into the key-board of the Data Handling System. For this purpose, in each main traffic center and in the Harbour Co-ordination Center AXT-communication-exchanges are installed, which are coupled to each other.

Each workposition has a capacity of 6 radiochannels and 26 telephone connections for direct access, and of course public telephone. For example: Central Traffic Control has direct lines with the City Hall, police headquarters, firebrigade, health service, environmental control, traffic centers, pilot organization etc.

All verbal communication exchanged via this system is recorded on 33- and 44 channel voice loggers, installed in the HCC and the main traffic centers. The (full) tapes are kept for one week and then erased, unless the information is needed.

**Data handling**

The Data Handling System is just developed. Before, us was made of a temporary system coupled to three closed telexnetworks to exchange the necessary information.

The new system is modular in design. The vessel guidance module is coupled to the tracking system and to the traffic control module. Information exchange with the tracking system encompasses ships data and voyagedata (received from traffic control) and ships position data. The output is information on vessels sailing in the area, ships expected in the area (ETA's), ships leaving (ETD's) and expected times of passage of certain boundaries.

The traffic control module contains all data on vessels, berths, agents, voyages, services ordered etc. It has a loose interface with the dangerous goods module, from which it receives a clearance advise for ships with dangerous cargo. The decision to permit a vessel to enter the port is taken by the Central Traffic Controller.

The dangerous goods module contains data on dangerous substances, the whole administration accompanying ships with dangerous cargo, permission for tankcleaning, repair etc. To assist the dangerous goods inspectors in taking (routine) decisions in accordance with the rules, use will be made of a special expert system.

The hydro-meteo module interfaces with own sensors (visibility meters) and the Rijnmond Hydro Meteo Center for other data like waterlevel, wind, weatherforecasts, gale warnings etc.
Users of the system are the VTS-crew, the deputy harbourmaster offices, the directly concerned organizations in the ships traffic like pilots, tugs, linesmen and the shipping agency Dirkzwager, and the indirectly concerned organizations: customs, riverpolice (immigration), Royal Netherlands Navy, harbourmasters of adjoining ports, the shipping inspection, the harbour labour inspection and the Department of Transport.

The information from the system is also used by the Port Authority for statistical purposes and for calculations of port- and quay dues.

A direct coupling is foreseen with the ship reporting system of the Department of Transport, covering the main inland waterways in the Netherlands.

Technically the tracking system is built on a network of 7 VAX-computers with more than 100 P800-computers as front-end machines. The data handling system is built on a network of 20 SUN-workstations and a (central) STRATUS-database server. Both systems, which are loosely-coupled, are decentralised over the 5 Traffic (sub-)centers and the Harbour Coordination Center.

The VTS-system is practical fault-tolerant. The STRATUS-computer itself is fault-tolerant, the VAX-computers stand in a hot-standby construction (MIRA), the SUN-workstations are completely compatible, the local area networks are doubled, the wide area networks are ring-nets and all the equipment is "provide" of an emergency power supply.
The VTS definition

VTS can be characterized as a set of functions. According to the IMO-guidelines a VTS can have the following functions:

I  Data collection.
    By means of radar, radiodirection finding (RDF), Closed Circuit Television, ship reporting, shore information from agents and shipping companies, weather reports etc.

II Data evaluation.
    Processing of collected data, translating into traffic situations, hydro-meteo conditions etc.

III Information service.
    Traffic information to ships and shipping-intelligence to shore organizations.

IV Navigational assistance service.
    Assistance to ships in confined waters or in difficult circumstances.

V Traffic Organization service.
    Planning of traffic in order to avoid traffic congestion and promote the optimal use of port resources.

VI Support of allied activities.
    The definition of VTS adopted in the IMO guidelines reads as follows:
    "Any services implemented by a competent authority to improve safety and efficiency of traffic and protection of the environment. It may range from the provision of simple information messages to extensive management of traffic within port or waterway."

This summing-up reveals that information exchange, communication between shore and shipping, as well as between ships is the most important aspect of VTS.
Literature:

1. The Vessel Traffic Service (on the Annual meeting of Radio Technical Commission for Maritime Services - Orleans may 1990 by Peter P. Noë and Jan C.M. de Keijser)
3. Ship Operation, Simulation, Training and Automation

3.1 Education, Training and Simulation

3.2 Quality Assurance

3.3 Voyage Optimization

3.4 Maintenance, Reliability and Safety

3.5 Ship Automation
SEC, MAATWERK IN DUURZAAM DECK EQUIPMENT.

Ship’s Equipment Centre, kortweg SEC, is de gebundelde kracht van vijf gerenommeerde producenten op het gebied van scheepssalfrusting. Met als specialisme: het leveren van duurzaam Deck Equipment.


SEC DECK EQUIPMENT KEEPS WORKING LONGER

SHIPS EQUIPMENT CENTER

Produktien van SEC: Ton Horn Lieren, Pool Ankers, Conaval Containerhellingen, Maritt Kranen, Macor Scheepsluiken.
Education, training and simulation
K.R. Damkjaer

Training and Simulation

The STCW Convention which came into force in 1978 is by today recognized world wide as a common standard for training and education of seafarers.

The Convention was prepared during the 1970's to establish a training and education régime for seafarers serving in ships built to a design developed during the Second World War.

Since the Convention came into being and until the late 1980's we experienced one of the worst recession in shipping ever. During years of recession the development of a high tech, low manned ship design gained ground, and today more and more ships are build in accordance.

Training Standard in the STCW Convention has to a large degree been outdated by the high tech ship and seafarer. New training methods and means - of which simulation seems to be the most significant single one - are urging for implementation.

This paper are defining what separates the training needs of today from the needs of the future.

The total crew concept is described and areas in which the use of simulation can assist and improve training efforts are defined.
Education and training of today's seafarers are in most seafaring countries regulated by the International Maritime Organization's (IMO) Standards of Training, Certificate and Watchkeeping Convention (STCW) which was adopted by the Organization in 1978.

Before the finalization of the convention, work within it had gone on for almost 10 years.

The convention has without doubt played a tremendous role in raising standards of training and education of seafarers. With more than 80% of the world fleet being contractors to the STCW convention it might be assumed, that seafarers plying the oceans do have the necessary skills to do so in a safe way!

Casualty and accident reports and statistics are giving another picture which questions the assumption just mentioned. It is widely acknowledge, that around 80% of all accident or casualties at sea are caused by the human element.

That this percentage is not just anecdotal is revealed by more and more studies of which on e.g. concludes, that human element was found present in over 90% of collisions and groundings, and in over 75% of contacts and fires/explosions.

Exactly the types of casualties which most presumable could be avoided by having the correct training and education system and regulation on watchkeeping on both navigation bridge and engineering room present. Precisely the intentions of the convention.

A variety of questions are frequently raised on that background. These questions can be categorised in 3 main groups as follows:

1. Standards set up in the STCW convention are too low.
2. Standards set up in the STCW convention are sufficient, but contracting governments do not comply with them.
3. Standards described are desirable, but not achievable with the means of today's STCW convention.

Before addressing questions 1 - 3 it might be appropriate to look at the convention in details, and more particularly to look at the education and training philosophy on which the convention is based.

The STCW convention is built on a traditional English system of training where young persons are indentured to become master craftsmen in 4-5 years. This system was adopted in shipping in late 19th century.

The system proved successful due to the slow pace of evolution of ships design and long periods spent at sea onboard the same vessel.
which ensured that apprentices were indentured to the same master for the whole training period.

Seafaring and seafarers encountered many unexpected problems, and solutions were often based on intuition and experience.

Training people to such an environment was well suited by the indentured system which was carried along without being questioned all the way into the 1978 STCW convention.

Education system in the convention is based on an academic approach where competence is achieved at college and is directly related to time spent in college.

The traditional departmental division is furthermore laid down in the convention, in such a way that competence and training are divided into separate hierarchical systems.

The convention itself does not only describe how to train and educate seafarers. It also regulates working and watchkeeping arrangements. It is, when discussing the convention, essential to draw a distinction between standards of training and education and standards of carrying out onboard duties regulated by the convention.

Standards of training and education are presumed to be the means by which the standards of working and watchkeeping are secured. By the intention of the convention it is understood that the aim of the standards in supporting one another is to establish a faultless operation.

More than anything else casualty statistics demonstrate that the convention has not been successful in that respect.

Before returning to question 1-3 formulated in a former section, it is appropriate to elaborate on the meaning of standards within the convention, in preparing answers to the questions standards are being discussed as well.

Are standards to low as indicated by Question 1?

It is hard to give any firm answers to this suggestion, as the necessary standards are changing with the technical development. The main problem seems to be that the convention is covering education, training and operational standards in ships which only have ARCHIMEDES’ PRINCIPLES in common.

Standards are for a traditional ships design with a traditional complement of crew in many ways acceptable with the current convention, but out of place for high tech ships as the Germans "shiff der zukunft" and the Danish "projekt skib" which is a design rapidly gaining ground throughout Western Europe.
In some areas, both traditional and futuristic ships design are profiting of todays technology which was not foreseen at the time of setting up the convention.

For instance a lot of emphasis is placed on navigation officers ability to establish their position on the globe and their ability to find their way. All this is today carried out by pressing buttons. These developments are not reflected in the way navigators and operators of navigation systems are trained and educated by today. This is more highlighted particularly in discussing question 3.

Question 2 is the most simple to deal with as it is not only commonly agreed but also well documented that some governments are all too lenient in interpretation of the convention and in issuing certificates to their seafarers.

The answer to this problem is, on the other hand, not to establish a new examination board within the auspices of the port state control which could be the implication of the proposals of having operational checks carried out by port state control inspectors.

Question number 3 is far the most complex one, but also the one which is addressing most of the problems faced by the convention. As mentioned the intention is not in this paper to describe or redescribe standards, but to look at how they are presently achieved and assessed, and most importantly to give consideration to change.

Assess technics as proposed in a coming section will apply to both the standards of todays convention and a revised convention.

Mr Juan Kelly is in session 7 B dealing with the training of tomorrow and the need for revision of the convention, and with it the need for reestablishing the standards.

3 different kinds of standards are described in the existing convention, namely

Standard of experience - experience mostly gained by training.
Standard of education - education as an academic learning process.
Standard of duties.

Experience is gained by seatime. The convention states that so and so many months have to be spent in a specific capacity either to obtain a higher certificate or to gain experience to get access to an education.

In gaining experience to qualify for an education some possibility of equivalating seatime with programmed training are allowed, but the convention is by and large trapped in the old snare of equaling time spent with experience.
Furthermore it is appropriate to question if the old tradition of working one's way up the hawse pipe is justifiable in today's shipping. As described in a former section, this way of training seafarers is reminiscent of the old training system well suited to ships of sails and paddles.

With today's ships and ships of the future, training efforts should be concentrated on subjects important to work carried out by the single individual.

Education is gained by classroom instruction and the final product is assessed by sitting an examination where the candidates' performance is measured by the ability to reproduce the syllabus.

Standards of duty are supposed to be fulfilled, if people trained and/or educated by the convention framework are carrying out the duties.

This is a well organized, but wholly academic approach which at its best is outdated and at its worst directly dangerous.

Even within the framework of today's convention, new ways of training, education and duties must be implemented.

In doing so we have first of all to realize, that today's seafarer is more and more becoming an expert operator of more and more complex systems. Training and education have to be focused on that fact.

For other reasons it might be desirable to train seafarers in academic disciplines e.g. to have the right number of administrators with a seafaring background available at any time, but it should not be dealt with by the convention.

The result of changing focus from academic education to training of operators could very well be a shortening of time spent in training and education, and at the same time an improvement of standards.

Training of operators requires simulators, and time has come to abolish the view of simulators being sophisticated tools for training captains and chief officers in delicate maneuvering techniques.

Simulators will for two reasons become one of the main tools for training seafarers:

First because they can replace today's accidental gaining of experience, and second because they are the most natural tool for training operators of complex systems.

Navigation, colreg, shiphandling and watchkeeping duties can be trained in a simulator in one sequence with an increasing amount of stress laid on the operator/trainee achievement which can never be
reached in classroom instructions with textbooks and wooden models.

The same applies to engineering, engine controlroom, operations, cargohandling and communications.

Instead of sitting examinations, the candidates' ability can now be assessed in the simulator giving a much broader picture of his or her behavior as an operator.

As mentioned before there are a very wide gap between the traditional ships design and the high tech ship design. Where the traditional design can be seen as the final stage of a long evolution in developing designs, the high tech ships must be seen as revolutions.

A revolution has also happened regarding the crew, but unfortunately it remains a well kept secret.

The high tech ships are referred to as low manned ships. It is thereby understood to many or most one could argue, that they are manned by a traditional complement of crew cut off in numbers from the bottom so to speak, but with the traditional division between officers and ratings and departments.

Sailing the world's largest reefer with a total of 7 as is done by the Danish Lauritzen Group demands a team instead of a complement of crew. Within the team you have to take full advantage of single individuals' experience and competence when delegating the work load onboard, doing it in a traditional hierarchical way department by department, would in days moor these ships up alongside quays.

The team onboard is being backed up by a team and other experts ashore, together forming the total crew.

In summing up there is a need for within the existing convention to review how competence and experience are assessed, understanding that paper qualifications do not necessarily confirm that a person is competent. Furthermore it has to be realized that competence and experience can not be counted on a day by day basis, accumulating to excellence.

Simulators have to become a main tool for training, and education must be directed towards the training needs.

Shipboarded duties as watchkeeping should be allowed to be carried out in accordance with the level of automation onboard.

Instead of focusing on bits and pieces in the industrial system, a review of tasks should be carried out to establish the need of training and education to ensure that seafarers are capable for carrying out the tasks in a safe manner.
It is, so to speak, necessary to turn things upside down, assessing the demand to the output, and from that point work your way down in a training and education scheme taking advantage of today's high tech media to ensure the highest level of competence.

With the new regulation 1/5 of the STCW convention an opening has been made, and it is now actually possible to establish the before mentioned changes with the existing convention.

One could on the other hand fear, that changes as has happened with the sole look out could be twisted and turned for so long in the drone of the IMO machinery that the convention could end as not just outdated, but as an museum piece.
The effect on marine safety of men, machine and regulations

J. Froese

ABSTRACT

There is quite a large range of measures available to improve marine safety, however, demands will not always be satisfied. Within this paper some weak areas within the man-machine-environment system, governed by rules and regulations, are highlighted. A simple model for detecting system disturbances is presented and clues for improvement are given.

MARINE SAFETY

The significance of safety within ship operation, similar to probably most other fields of professional activities, can in some respects be compared to religion: everybody confesses verbally to be convinced of and to follow established rules at all times but only some really do so. Operators and workers often feel bothered by the restrictions caused by safety rules and owners and managers regard safety mainly as a cost factor the benefits of which are very difficult to realize. Therefore the significance of safety is about that of law. Most people reluctantly accept its necessity but take every opportunity to bypass established rules.

This is certainly a provocative introduction but within a paper, which has to be brief and concise, provocation should present a permitted means to elucidate circumstances and to stimulate discussion.

The term marine safety is somewhat vague and will be understood within this paper as "all measures and conditions minimizing potential dangers and harm to men, objects and environment which might be caused by operating vessels". Safety measures can be established within different areas:

- technical measures and provisions when manufacturing a system, or when operating a system,
- organizational measures within a working process and
- behavioural measures when operating a system.

Additionally passive measures, such as man protection by special clothes (hard hat etc.) are possible.
There are three groups of people to be protected by safety measures: the operators directly involved in the working process, the co-workers and company members only indirectly participating but having some chances to observe and influence the working process and hence safety and finally those third parties not being involved at all but who might become exposed to results of incidents. There might be important interactions between all three groups by either checking the working process or specifying requirements.

An important aspect of shipping is that vessels are necessarily moving around. Third parties might not even become aware of potential dangers, and that shipping is an international business under tough competition. Thus there is little access for improvements on a national basis only.

As a rule, only spectacular events draw the attention of the public to certain conditions. Such casualties as the grounding of the "EXXON VALDEZ", the capsizing of the "HERALD OF FREE ENTERPRISE" and the fire aboard of the "SCANDINAVIAN STAR" have caused more doubts about shipping operation and performance than the large number of smaller incidents. One should make advantage of the increased willingness of owners, operators and administrations to improve marine safety resulting from such spectacular accidents.

LEGAL ASPECTS

The whole human life is accompanied by laws and regulations to obtain order and justice within society. Our modern society is considerably influenced by technique. Technical rules therefore have to be part of laws and regulations. However, this requirement leads to a contradiction. Whereas technique is a dynamic subject, experiencing fast changes, the legal system is rather static, it follows general developments only very slowly. This is mainly due to the time democratic processes require to establish and modify law. However, it is not only a disadvantage but also a benefit regarding legal security and citizens' confidence into law. As a result it can be said that law and regulations will never be able to precisely define all facts and circumstances arising in practice. Technique, however, must be specified in great detail.

Besides the preventive character of law and regulations clear and unambiguous principles are needed to decide after an incident who has to be blamed and, more important within business life, which persons or parties are to be held liable for damages. Since the more general legal comments seldom allow for a simple decision on who is to blame, a whole bundle of tools was developed to supplement laws and regulations.

The state of the art describes in detail how a technical system should be constructed and how it should function and be operated. Agreed standards worked out by privately organized bodies cover a large area of details but are not always up to date. The performance of standardizing bodies is not very different from legislative bodies and therefore comparably slow. Thus a vast market was created for experts, the consultants. There is quite a number of private consultants offering their services but also institutions, normally dealing with a certain professional area, are willing to provide their knowledge if required. Therefore law and regulations only present the shell of the operational system, the real
content has to be added by mostly private efforts. If a case is brought to court, the legal procedure requires a lot of time and large budgets. Opposing parties both present their impressive staff of experts trying to convince the judge that the other party has to be blamed. The more the case goes into technical details the more the judge becomes dependent on experts. To remain provocative, this procedure well feeds a large number of people without guaranteeing justice.

MAN-MACHINE-ENVIRONMENT SYSTEM

To discuss improvements, a model of the process under consideration is required. Since ship operation is rather complex, i.e. complicated and dynamically changing, models, only presenting a static view of the process should be treated with care. On the other hand a model is an appropriate method to structure brain storming. But is must be emphasized that at the end a thorough validation is needed before putting the measures into practice.

Figure 1: Man-Machine-Environment Model

Figure 1 shows a man-machine-environment model including two loops, the internal vessel’s loop containing all shipborne technical systems and operations and the traffic and environment loop where the vessel constitutes only one element of a larger system. A specified application of the model requires more details depending on the purpose of application. The technical elements and their functions and operations have to be described, knowledge of organization and staff is required and available regulations, rules and recommendations must be considered. Actual conditions, sometimes changing very fast, then
must lead to cybernetic functions. Because different areas require different experts it is wise to agree on an a "shell model" hosting other more detailed models. At the end of every improvement process related to a special area one must come back to an overview for not neglecting undesired interactions between the area under consideration and others.

Figure 2: Simple Layer Model

Figure 2 shows a layer model to be applied for a special area such as e.g. a ship's bridge. Such a simple layer model is quite appropriate to detect disturbances which might lead to an incident or impair economic results of the system. The way through the model has be started at the bottom, describing technical equipment on level one.

The second level shall contain equipment functions as defined by the manufacturers themselves, found within manuals, maintenance books etc.
Looking back then to level one it must be checked if all technical modules, required by planned functions are installed and properly working. If this is not the case, disturbance level 1/2 can be specified.

On level three functions as required by tasks to be performed shall be described. Regulations, rules and recommendations having an impact on task performance must be taken into account.

If required functions do not absolutely match with available functions, disturbance level 2/3 can be specified. People not properly equipped for task solving act unsecure.

Level four describes the actual application and operation of said equipment observed in practice.

Often operators do not use technical devices according to operational rules or according to their assigned purposes. Thus, if level four does not properly fit onto level three, again possible causes for disturbances can be detected and described within disturbance level 3/4. On this level a concentration of causes for casualties will be found.

Level five contains details on staff, their formal qualification, experience and attitudes (behaviour).

Within an ideal working environment staff qualification should exactly fulfill operational requirements described within level four. Shortcomings may lead to damages and incidents, overprovision to frustration and reduced job satisfaction, and as a consequence also result in incidents. Therefore both cases shall be documented within disturbance level 4/5. It is argued that attitudes present the main cause for accidents, thus behaviour must be carefully investigated and deficiencies laid down within the same disturbance level, too. On this level another concentration of causes for casualties will be found.

Level six finally describes in detail objectives and tasks to fulfill these. The content of level three is derived from this level.

The described approach may already deliver desired results within a clearly limited area like a ship's bridge. If more complex areas have to be considered, additional levels resp. sub­levels reserved e.g. for regulations only might be required. The purpose of this example is to elucidate how models can be applied to determine interactions between different areas. A model is also an appropriate means to clarify desired systems performance and objective. Under ideal conditions the different levels of the layer model fit exactly upon each other. Although this never happens in reality the knowledge of disturbance levels helps to become alert in time and thus to avoid undesired events.

**IMPROVEMENTS POSSIBLE?**

An overall objective within marine safety is to improve conditions before they can lead to an incident. A well approved approach to obtain this goal is the **analytical method** based on
models as briefly explained the preceeding chapter. The disadvantage of this methods is that it requires considerable efforts and results are not always satisfactory because not all circumstances encountered in reality can be forseen. Therefore the outcomes from casualty investigations play an important role to improve theoretical analyses. By studying incidents having occurred in reality one becomes sensitive for combinations of conditions and circumstances resulting in inherent potential dangers. This certainly sounds obvious but it is very difficult to do in practice.

There are the aspects of civil law, i.e. liability which the parties involved are mostly concerned about after a severe marine accident. And it is common procedure to hold back any information which could be used by counterparts, thus results of court cases much more demonstrate the ability of lawyers than elucidating causes and conditions of a casualty. If we really want to learn from marine incidents, to reduce the number and severeness of future ones, the marine casualty investigation system has to be changed. Probably a lot can be learnt from the aircraft industry where independent investigation offices immediately commence their search for causes and conditions after a crash or even in case of a near-desaster. Their most important source of information is the flight recorder providing all relevant data.

Some shipping countries, too, have qualified investigation bodies but in general they lack authority power and budgets. And there is hardly any other possibility to obtain information than by interviewing people very reluctant to clarify circumstances. Other serious constrains are national responsibilities leading to quite different treatments of a cases and often enough national sovereignty is rated higher than common interest to avoid marine desasters. A severe pollution will disregard national borders and so should not casualty investigation offices.

However, competent investigation does not only call for efficient administrations, access to scientific institutions dealing with relevant areas from computer science to psychology is a must. The ideal solution would be an investigation office operating jointly with a maritime rather than a marine research facility. Practice changes so fast nowadays that an investigation cannot be based on the experience of former seafarers, as it was common practice so far.

SIMULATION OF THE MAN-MACHINE-ENVIRONMENT SYSTEM

When applying an appropriate model of the man-machine-environment system or a relevant part of it, all physical facts can be calculated. If this is done by computer feeding the model with data and processing its algorithms this is called simulation. If this process can be performed faster than in reality because of the high processing speed of a computer, this kind of simulation is called fast-time simulation. There are several such tools available relieving us from the burden of endless calculations.

However, within the man-machine-environment system man plays a key role. To reliably assess this role, simulated processes must be run in real-time. Within an appropriately designed working process as e.g. navigating a vessel along a fairway, ideal routine workload
conditions result in perception, mental processing and decision sequences which require about 70% of the operator’s capacity. Higher workloads would occupy remaining capacity which should be reserved for extraordinary situations or even overload the operator, i.e. he is liable to miss vital information or actions. Considerably less workload may lead to boredom and fatigue and hence also to reduced perception of vital information. Real-time ship simulators provide an ideal environment to investigate the influence of technical, organizational and behavioural factors on performance of human operators. Figure 3 gives an overview over methods of ship simulation and figure 4 shows an example of a simulator allowing for full mission performance.

Figure 3: Methods of Ship Simulation
Figure 4: Full Mission Ship Simulator (SUSAN Hamburg)

The controlled conditions within simulation and the possibility to observe performance, to record all relevant data and interview operators provide good access to all operational processes. However, there is no guarantee that operators in simulation behave exactly in the same way as they would in reality. There are some hints that e.g. rules will be less often violated in simulation because probands feel surveilled. Therefore all obtained results require verification.

There is an additional advantage of operating a ship simulator for training and research purposes, which should not be underestimated. Whereas seafaring normally takes place remote from investigating bodies and hence assessment projects are very time and budget consuming and will cover very limited areas, a simulator provides a constant discussion.
platform with seafarers and other involved persons like pilots, tug masters, vessel traffic management system operators, administration people etc.. Acting persons change quite often, thus a broad spectrum of skills, knowledge, attitudes, experience and opinions is provided. From about 10 years of experience within such an environment some remarks on the effect on marine safety of men, machine and regulations can be made.

SOME REMARKS ON THE EFFECT ON MARINE SAFETY OF MEN, MACHINE AND REGULATIONS

It is argued that the safest ship operator is an appropriately educated and trained beginner! Such a person certainly lacks experience and self-confidence but is extremely alert and willing to ask for the master's assistance whenever uncertainties arise. The more experience without serious incidents is gained, the more people tend to become overconfident, resulting in unsafe attitudes. It was proven [1] that special training aiming at improvement of performance led to an increased number of accidents. The theory behind such surprising attitudes states [1], that men estimate actual risk and compare it to accepted maximum risk. Then e.g. a car driver after having participated in a special driving training programme will drive at higher speeds and accept more dangerous situations than before because he feels he can cope with these. The same applies to increased technical safety. Thus the invention of radar or later ARPA did not reduce collisions. To again apply an example from car driving, German car insurance companies allowed for a 10% premium bonus for cars equipped with automatic brake systems (ABS) but that was cancelled after 1 year because it clearly showed, that those cars were significantly more often involved in accidents. It therefore must be accepted that increased safety cannot directly be obtained from either better training or better equipment. This should not mislead to not investing into both areas. What we must learn from stated experience is that parallel to those investments both, individual overconfidence and risk acceptance level must become reduced by behavioural measures.

It seems that simulated reproduction of conditions which led to severe incidents results in improved awareness of potential dangers and hence safer attitudes. Practioners often are surprised when learning that most accidents are not preceeded by unambiguous warning signals but are generating out of conditions experienced every day. It is, however, felt, that such improved attitudes may fall back very soon (compare behaviour of car drivers passing a serious road accident; they tend to drive slowly and carefully just beyond the site of the accident but get back to their original behaviour after some more kilometers).

The more complex technical systems become, the more difficulties will men face to build up a "mental model" of what happens within all those "black boxes". This is no problem as long as systems applications and output exactly fit to operational conditions. Technical disturbances or unexpected situations, however, require actions diverging from routine. The operator then will experience difficulties in estimating which system inputs will lead to which results. Whereas routine operations ask for a selection from known alternatives, he is suddenly confronted with a real problem solving task, difficult to be mastered if acting within a complex system, the functions of which are not well understood. It is therefore recommended to allow for cutting off automated interfaces between system components and modules to give the operator a chance to get right into the process and view processed
results from known inputs. It is further recommended to simplify systems. This will not only lead to an easier understanding of system's functions but also result in less malfunctions and alarms.

Whenever searching for improvements of marine safety it must be understood that, different from most other operator tasks, within navigation it is impossible to foresee necessary actions. Internal systems interfere with outside conditions and a larger number of parallel actions concerning completely different areas and objectives might be urgently required. Furthermore most external information can only be perceived by man's visual or aural "input channels", i.e. eyes and ears. No technical sensors allow for automated perception. These circumstances shall support pleading for rigorous simplification of systems and abandonment of all "nice to have" features in favour of systems and functions covering just what is required.

Regulations, rules and recommendations from administrations, company owners and others seem to rather aim at having an excuse at hand if something goes wrong than supporting practice. The often cited "Standards of Training, Certification and Watchkeeping (STCW)", an IMO document adopted by most seafaring nations, presents a good example. All administrations feel happy about having established the standards believed to ensure sufficient qualified seafarers. In fact these standards are only guidelines giving a rough idea of rather the objectives than clear and unambiguous requirements. The minimum knowledge required for certification of masters and chief mates e.g. amongst many others reads: "Understanding fundamental principles of ship construction and the theories and factors affecting trim and stability and measures necessary to preserve safe trim and stability." [2] It becomes obvious that the terms "understanding", "fundamental principles", "factors" and "measures" will be interpreted fairly divergent and little "standard knowledge" will result from such guidelines.

The IMO Sub-Committee on Safety of Navigation within its report on 37th session from 4th October 1991 negotiated the topic "bridge procedures". One member state proposed to standardize procedures and to promote procedure training and procedure handbooks, check lists etc. on board.

There is certainly nothing wrong with that approach but from experience it is likely that finally the poor mariner will just receive an additional manual for his book shelf on the bridge already flowing over from piles of paper nobody can know by heart anymore. It is obvious that when suddenly confronted with extraordinary conditions no mariner is able to search for books showing how to cope with the situation. However, after having experienced a casualty he will find himself at the court of inquiry where the experts, after having studied the files for some days, will name him all the paragraphs he has neglected within that period of a few seconds he had available to decide. Within shipoperation we have reached a situation where we should have the courage to get rid of a big portion of regulations and find back to clear and unambiguous rules. But that will remain wishful thinking as long as administrations even maintain rules they have already recognized as being superfluous. E.g. when navigating along fairways a number of nations do not allow for autopilot steering. Pilots, however, preferring a successful voyage to just following the rules, regularly apply autopilots. After an incident courts of inquiry then often, accepting this performance, just
autopilots. After an incident courts of inquiry then often, accepting this performance, just ignore that violation of the rules during the hearing.

But how to perform better? Just skipping all rules and regulations will certainly not lead to desired results. What is required most urgently are accepted standards of performance. The navigator must be told how to assess a situation and then to decide on "safe distance", "moderate speed" or "prudent seamanship". That is, however, much more difficult than it sounds. For years experts have been trying to work out such standards but the results obtained so far are not too convincing. Again simulation obviously provides a tool to improve the situation. By experiencing pre-defined situations and reproducing these as often as required applicable standards might be worked out, a task which really calls for cooperation amongst simulator operators and other experts.

CONCLUSION

Marine safety is a matter of public concern. Administrations and owners do not feel very comfortable facing potential disasters and therefore generate activities leading to additional technical features, organizational measures and regulations. One must doubt, however, if these activities will finally result in real improvements, i.e. fewer casualties. Improved marine safety requires measures generated within the system and really fitting to it not only trying to affect it from outside. Efforts must comprise the seafarers social and economic situation. As long as modern vessels worth far more than a hundred million US dollars and carrying cargo of about the same value are manned with crews receiving salaries hardly adequate for unskilled labour not too convincing results can be expected.

LITERATURE

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The use of simulators in training and port design

F.E. Guest

Abstract

Two examples of the use of ship simulators are examined. The first example describes the use of ship simulation in a recent training program called Bridge Resource Management. Modeled after similar training in the aviation industry, it is a program employed by oil companies to train their tanker officers. This training includes a new concept in the maritime industry of the United States: demonstrated proficiency.

The second example looks at a ship simulator being employed to test a port design. The engineering design for the deepening of Kill van Kull in New York harbor was tested by real time simulation with actual pilots. After the testing of the design it was realized that the sequence of dredging also had to be tested by simulation.

The examples were selected to demonstrate that the technology of ship simulation has reached a mature stage in its development. Maturity is realized when the technology has become essential to the industry it serves and when further, new applications of the technology, suggested by those in the industry who are the recipients of its service, are immediately available.

Introduction

The purpose of this paper is to use two examples to illustrate the current state of the practiced art of applying ship simulation to training and port design and to demonstrate that ship simulation has become a mature technology.

It is an accepted fact that ship simulation has been and is being used in an effective manner as a tool for the training of mariners and for the testing of port designs. MarineSafety International has been using simulators for training for over fifteen years and has been engaged in research by simulation for over five years. The larger history of the use of marine simulation goes back beyond the experience of MarineSafety, and, although an historical survey is beyond the scope of this paper, it is instructive to mention that the real beginning of marine simulation began here in the Netherlands in the 1960's. A ship's bridge simulator capable of doing both research and
training was in operation in this country as early as 1967 (Puglisi, 1987).

Yet although electronic ship simulation has nearly 25 years of history, it is only fairly recently that it could be said to be a mature technology. Even now the scientific underpinnings are still being called into question. A study conducted by the Marine Board of the National Research Council in the United States purports to examine what attributes a simulator should have to be able to conduct tests of port designs. That study will be published soon, but pre-publication reviews indicate that the Marine Board will ask for more research into some of the fundamentals of ship simulation: adequacy of mathematical models, methods of validating data bases, interpretation of simulation results, and so forth. Still, on a higher cognitive level, recent examples of the use of ship simulation technology seem to provide evidence that the technology is essential to the marine industry and that it is being applied effectively in areas not thought of before. Such acceptance by industry would seem to indicate a level of maturity, if only recently.

Before looking at two specific examples of the application of ship simulation, it would be beneficial to define the terms which are referred to in the title and which will be used throughout the paper.

Simulators: This term refers only to ship’s bridge simulators, the type which replicate the bridge structure, the instrumentation and controls, and a lifelike out the window view. This is known as a Full Mission Bridge simulator (FMB).

Training: This is the purposeful exercising of professional mariners in the tasks which they will be called upon to perform when standing watch, piloting, or shiphandling.

Port design: This refers to the operational and engineering plan of a port authority or engineering/dredging authority which reflects proposed improvements in a harbor or waterway. Examples would be such things as deepening a channel, locating new terminal docking facilities, establishing different harbor entrance policies.

Thesis

Real time ship simulation has developed to the level that it now is beginning to change the way one thinks about maritime training and harbor development. More than just a tool, the simulator has become an agent for change and, because simulators exist and have reached a level of sophistication, are now opening new vistas of how they may be used to assure safe operations and a cleaner environment.

This phenomena of a technology becoming a change agent is not
new. It often happens that systems technology developed for a specific application itself becomes a reason for doing or changing something beyond what was originally intended. This is especially true of high level systems development wherein several different technologies are married for a specific end. For example, computers, which use the technologies of television, electrical power, and microchips, were originally developed to ease the burden on scientists and engineers for making long, involved and difficult calculations. But computers, without belaboring the obvious, have become useful for a plethora of applications beyond mere calculation. It appears, in fact, that the existence of highly developed computers has caused us to visualize and think of applications which would not have been thought of unless and until the computer system existed. Computers have certainly eased the burden of calculation, but they have also been applied to other human endeavors as well: drawing, writing, publishing, medical diagnosis, and an endless list of actual and possible applications.

The systems technology of real time ship simulation has now developed sufficiently that it has entered this same era when the technology itself suggests applications not previously thought of. One might say that this phenomena is indicative of a technology that has attained a certain level of maturity. Although it has only a brief history, the systems technology of electronic, real time, full mission ship simulation is at this mature stage.

Training
Evidence for this thesis is found in the training and in the port design applications of ship simulation. In the training arena it must be observed that the focus of training has changed since the advent and the maturing of marine simulation. Simulation has been a good tool for helping to train pilots, shiphandlers, and watchstanders, but beyond that, full mission ship simulators are changing the way training is conceptualized. Training has left the conceptual framework of "the gaining of information and acquiring of skills" and entered the realm of "practicing the operation to become as proficient as possible".

Port Design
In the same manner, the application of simulators to port design work has left one realm and entered another. Simulators have in the past been used to examine the safety or navigability of an engineering design, now, as will be seen in the provided example, they are being used to assess the process of building the previously tested design.
Example 1: Bridge Resource Management Training

Shortly after the Exxon Valdez accident, Exxon Shipping Company contracted with MarineSafety International to design and implement a training program to be taken by all of its tanker officers. The training took place at MarineSafety’s Newport, Rhode Island training center.

Recent studies had shown that most ship casualties were not caused by a lack of technical knowledge but rather by a weakness in human factor or "people" skills in the areas of bridge teamwork and procedures, communications, situational awareness, stress management, and the like. Simply stated, the bridge teams were not properly managing all the available resources to keep their awareness sharp.

This problem of low situational awareness was seen first in the aviation industry. Accident investigation there revealed that airplane mishaps were in a great majority of the cases the result of poor cockpit crew performance and low situational awareness. It was quickly realized that there was a need to train the flying crew as a team. The training and development of individual skills and knowledge had before been the primary focus of all training programs. Now it was apparent that team skills had to be developed to assure that the cockpit crew maintained good situational awareness. The result was a course of instruction known as Cockpit Resource Management (CRM). This training emphasizes teamwork, communication, procedures, stress management and conflict resolution. It also deals with case studies which dramatically demonstrate how low situational awareness in the cockpit resulted in catastrophic accidents. CRM training was adopted by many major airlines. It has now become a required training program for aviators in the United States, according to the Federal Aviation Administration.

As part of the development process for the Exxon course, MarineSafety went to its parent company, FlightSafety International, for assistance and insight. CRM and the elements of that training which emphasized general human factors skills were adopted into the Bridge Resource Management course.

In addition to adopting elements of CRM into its BRM course, MarineSafety investigated the way FlightSafety measured and documented the proficiency of individuals. Part of the requirements of Exxon was that each of the deck officers attending the course would be individually rated.

Course objectives and methods
The objective and methods of the course are to build bridge team management skills by placing ship’s officers in a sequence of simulated voyages which duplicate both the routine and emergency demands that they are likely to meet in the real world. Through a series of lectures, briefings, debriefings
and critiques, the officers are drilled in standard procedures and methodologies for handling a wide variety of challenges to the bridge team. A training schedule is shown in Figure 1 (Seitz, 1990). This course has been adopted by several other shipping companies and at least one tug-barge operator. It has also been recognized by the U.S. Coast Guard. Those successfully completing the course are considered by the Coast Guard to have gained 30 days deck watch officer credit toward any U.S. merchant mariner’s license or document endorsement.

Proficiency rating
A unique part of the course is the rating of individual proficiency. Each day, each person on the course is rated by the instructor working with that person that day. Figure 2 represents the typical rating sheet. The rating is rather straightforward. A number "1" placed by the instructor into one of the columns means that the trainee is able to perform that maneuver, procedure or other requirement properly and safely and has a full understanding of the procedures or principles involved. Number "2" placed in the column means that the trainee is making satisfactory progress towards proficiency and should achieve full proficiency by the end of the present course of instruction. If the instructor selects a number "3" it means that the trainee is not progressing well enough to reach full proficiency by the end of the present course of instruction. Special attention is required to accelerate the rate of progress.

To earn a certificate of completion, the trainee has to achieve a proficiency rating of "1" in every category by the end of the program of instruction. This rating, of course, is made with the experience level of the trainee in mind. However, when a person is rated as not proficient in any category, documentation and recommendations for resolving the deficiency are prepared in consultation with the company representative, and remedial action is taken. Decisions about those who do not achieve the proficiency rating include (depending on the company involved): further training at a later date, demotion to a less responsible position on the bridge team, or removal from the bridge team position.

The rating of individual proficiency is a new factor in the training of professional mariners in the United States. As expected, there was a measure of resistance to the idea. The resistance soon relaxed, however, probably because of the following reasons:

First, the rating was done by mariners who, in addition to being qualified simulator instructors, had an experience level above that of the persons in training.

Second, each person in training was rated daily by a different instructor, thereby helping to remove any closed mindedness on the part of any one instructor.
<table>
<thead>
<tr>
<th>DAY ONE</th>
<th>DAY TWO</th>
<th>DAY THREE</th>
<th>DAY FOUR</th>
<th>DAY FIVE</th>
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<tbody>
<tr>
<td>SIMULATION SESSION ONE 0600-0900</td>
<td>INTRODUCTION &amp; FACILITY TOUR</td>
<td>SF-12 [MINI VOY: OFFSHORE SAN FRAN TO ANCHORAGE 9) - 76K (Ld)</td>
<td>VAL-1 [ARR CAPE HINCHINBROOK) - 209K (Bal)</td>
<td>VAL-12 (EXXON VALDEZ SIM STUDY)</td>
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<td></td>
<td>SLALOM-1 (SIM SAIL)</td>
<td></td>
<td>VAL-10 [MINI VOY: BLIGH REEF TO PORT VALDEZ) - 209K (Bal)</td>
<td>Exercises per option of instructors/trainees</td>
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<td></td>
<td>ARPA DEMO</td>
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<tr>
<td>COFFEE BREAK</td>
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<tr>
<td>SIMULATION SESSION TWO 0900-1200</td>
<td>SF-14 [MINI VOY: ANGEL ISLAND TO BENICIA) - 78K (Prt Ld)</td>
<td></td>
<td>VAL-11 [MINI VOY: PORT VALDEZ TO BLIGH REEF) - 209K (Ld)</td>
<td>Exercises per option of instructors/trainees</td>
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<td>Trainee Course Critiques</td>
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FIGURE 2 - BRM Trainee Evaluation Sheet

<table>
<thead>
<tr>
<th>EXPERIENCE LEVEL:</th>
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<tbody>
<tr>
<td>MSTR</td>
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<tr>
<td>CURRENT LICENSE (CHECK ONE)</td>
</tr>
<tr>
<td>PRESENT POSITION (CHECK ONE)</td>
</tr>
<tr>
<td>PAST EXPERIENCE (INDICATE APPROX YEARS IN EACH POSITION)</td>
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</tbody>
</table>

<table>
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<tr>
<th>EVALUATION AREA</th>
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</thead>
<tbody>
<tr>
<td>1. KNOWLEDGE OF NAVIGATION POLICIES AND BRIDGE ORGANIZATION / PROCEDURES</td>
</tr>
<tr>
<td>• ESC NAVIGATION AND BRIDGE ORGANIZATION MANUAL</td>
</tr>
<tr>
<td>• ESC STANDING ORDERS</td>
</tr>
<tr>
<td>• UNDERWAY BRIDGE WATCH CONDITIONS/MANNING/TASKS</td>
</tr>
<tr>
<td>• UNDERWAY WATCH CHANGING PROCEDURES</td>
</tr>
<tr>
<td>• RESTRICTED VISIBILITY PROCEDURES</td>
</tr>
<tr>
<td>• FAILURE AND EMERGENCY RESPONSE/PROCEDURES</td>
</tr>
<tr>
<td>2. COMMUNICATIONS</td>
</tr>
<tr>
<td>• USES EFFECTIVE VERBAL COMM WITHIN BRIDGE TEAM</td>
</tr>
<tr>
<td>• USES PROPER VHF RADIO AND HELM ORDER PHRASEOLOGY</td>
</tr>
<tr>
<td>3. SITUATIONAL AWARENESS AND ERROR CHAINS</td>
</tr>
<tr>
<td>• HAS GOOD OVERALL AWARENESS OF NAVIGATION SITUATION</td>
</tr>
<tr>
<td>• RECOGNIZES ERROR CHAINS &amp; SHIP STANDING INTO DANGER</td>
</tr>
<tr>
<td>4. BRIDGE TEAM LEADERSHIP</td>
</tr>
<tr>
<td>• ORGANIZES BRIDGE TEAM</td>
</tr>
<tr>
<td>• TRAINS AND COACHES TEAM MEMBERS</td>
</tr>
<tr>
<td>• MAINTAINS AVENUES OF DISAGREEMENT WITHIN TEAM</td>
</tr>
<tr>
<td>• EFFECTIVELY MAINTAINS COMMAND (OR CONTROL) AUTHORITY</td>
</tr>
<tr>
<td>5. MANAGEMENT OF STRESS AND DISTRACTIONS</td>
</tr>
<tr>
<td>• UNDERSTANDS CAUSE/EFFECT OF STRESS AND DISTRACTIONS</td>
</tr>
<tr>
<td>• USES TECHNIQUES TO MANAGE STRESS AND DISTRACTIONS</td>
</tr>
<tr>
<td>6. VOYAGE PLANNING</td>
</tr>
<tr>
<td>• PREPARES A SAFE AND EFFICIENT VOYAGE PLAN</td>
</tr>
<tr>
<td>• PROPERLY MONITORS THE VOYAGE PLAN</td>
</tr>
<tr>
<td>7. MASTER-PILOT INTERFACE</td>
</tr>
<tr>
<td>• UNDERSTANDS MASTER-PILOT RELATIONSHIP</td>
</tr>
<tr>
<td>• CONDUCTS A PROPER MASTER-PILOT CONFERENCE</td>
</tr>
<tr>
<td>• EFFECTIVELY UTILIZES PILOT AS A MEMBER OF BRIDGE TEAM</td>
</tr>
<tr>
<td>8. SHIPHANDLING AND RULES OF THE ROAD</td>
</tr>
<tr>
<td>• UNDERSTANDS SHIPHANDLING FUNDAMENTALS</td>
</tr>
<tr>
<td>• MAINTAINS DESIRED TRACKLINE/SHIP CONTROLLABILITY</td>
</tr>
<tr>
<td>• PROPERLY ASSESSES WIND AND CURRENT FORCES</td>
</tr>
<tr>
<td>• PROPERLY HANDLES SHIP AT PILOT STATION</td>
</tr>
<tr>
<td>• USES PROPER ANCHORING PROCEDURES/METHODS</td>
</tr>
<tr>
<td>• UNDERSTANDS EMERGENCY STOPPING TACTICS</td>
</tr>
<tr>
<td>• UNDERSTANDS AND COMPLIES WITH COLREGS</td>
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</tbody>
</table>

INSTRUCTORS INITIALS (DAILY)

NOTE: REFER TO COURSE MANUAL IF EXPANDED DEFINITION OF ANY EVALUATION AREA IS REQUIRED

Expand with comments on the attached remarks sheet as required.

In the event that a trainee's rating is less than (2) = NORMAL PROGRESS, the remarks sheet must be filled out with an explanation of the deficiency.

SENIOR MSI INSTRUCTOR'S SIGNATURE (FINAL):
Third, each person met with the instructor doing the rating each day to discussed his/her progress. There were no "surprises".

Fourth, the person’s experience level was always a factor in the mind of the instructor. Less experienced persons (eg. third mates) were not expected to perform at the same proficient level as more experienced persons (eg. masters).

Fifth, it soon became apparent that the deck officers who were really concerned about being professionals welcomed the chance to show their proficiency and thereby readily accepted the daily rating sessions.

Conceptual change
This course demonstrates a conceptual change in the minds of ship operators and regulatory authorities. The idea of training has changed from the concept that training is the acquisition of skill and knowledge to the concept that training is the purposeful exercising of professional mariners in the tasks they will be called upon to perform, exercising those tasks to proficiency.

The conceptual change can be precisely described in three propositions as follows (Guest, 1990).

One: The Purpose of Training is Safety
Training was traditionally undertaken for reasons such as: a new piece of equipment had been put on board such as an ARPA or an Inert Gas System and persons had to learn how to use it, or there was a new regulation to be met, or a new ship was being built and the chief engineer and master needed to be familiarized with the engines and systems, or the ship was going to do something different such as lightering and the master needed some special shiphandling instruction. This is training for information or to learn something new or not before experienced, and this reason for training occupied the consciousnesses of those who were assigned the jobs to identify the need for and purchase training.

Now, however, there is a felt need for training for safety, meaning safe operations, and not just for information. The concern is for safer masters, mates, pilots, and engineers rather than merely smarter ones. Safety is a matter of proficiency in skill and in maintaining a high level of awareness. It is also a matter of good habits and a proper attitude.

Two: The Goal of Training is Proficiency
The focus of professional training is on proficiency. A proficient ship’s officer is, by definition, a safer operator.
It is interesting to note that no master, mate, pilot or engineer in the U.S. merchant marine has ever had to demonstrate proficiency in the skills necessary to perform in a safe manner to a governmental regulatory agency. Aviators, air traffic controllers, chauffeurs, and even bus drivers must each demonstrate proficiency. A licensed mariner, however, need only show evidence of experience and take a paper-pencil examination to qualify as competent to operate the largest "vehicles" in existence.

Before the advent of computer based simulation it was hardly practical to qualify individuals on the basis of demonstrated proficiency. It would have been too time consuming and expensive to dedicate a ship as a test base for qualifying exercises. Moreover, one ship would not have been sufficient because of the myriad of sizes and propulsion types in existence. Now, however, it is possible to train and test for the full range of skill, knowledge, and abilities in a fairly time and cost effective manner by using full mission simulation.

Three: The Means of Training is Simulation
Training for proficiency in individual and bridge team maneuvering decision making requires a sophisticated training environment. If safety is the "bottom line" for training, then the method of training for increased safety margins or, to say it another way, the method of training for reduced risk, is to have the persons in training make maneuvering decisions on a basis that is as much as possible identical with the basis on which the decisions are made in actual practice. This is training which calls for a full-fidelity training environment.

The advent of the full mission bridge simulator has made possible the training to proficiency, but, just as important, it has made possible the testing for proficiency. Before the advent of ship simulation the operators and regulators were satisfied to train and test for competency; that is, having the necessary minimum knowledge and skill to allow one to potentially make good operating decisions. Now, the operators and regulators have had a conscious change and are beginning to see that they can have training and testing for proficiency; that is, having the necessary ability and attitude to actually make good operating decisions.

There is a conscious change being wrought by the existence of ship simulation technology. Training is seen as something more than learning. Training is practice. Training is recurrent; that is must be done periodically in an officer’s career to achieve and maintain proficiency. Training with full mission simulation is the means of achieving proficiency. Training with full mission simulation provides for testing for proficiency.
In 1988 the U.S. Army Corps of Engineers contracted with MarineSafety International to conduct real time simulation tests of its design to deepen and widen certain channels in the port of New York-New Jersey. The port design study took place at MarineSafety’s Kings Point, New York research and training center. This center is also well known as CAORF, the Computer Aided Operations Research Facility.

In this port design study, simulation runs were conducted to investigate how the navigability of Kill van Kull/Newark Bay and Arthur Kill channels would be affected by proposed changes. These changes included dredging to a project depth of 40 feet and widening and realigning selected portions of the channels. The improvements were being made to accommodate larger and more deeply laden ships. Figure 3 illustrates the area under study.

Test plan
The overall test plan required that a minimum of six experienced New York Harbor pilots make at least ten simulated transits of the channels under study. Each of the simulated transits (also called scenarios) represented a unique test condition. The test conditions were selected by a committee of persons representing the interested organizations: the New York District of the Corps of Engineers, the Army’s Waterway Experiment Station (WES), practicing New York harbor pilots and docking masters, and MSI project personnel. Variations were made in current (maximum ebb or flood), wind (NNW at 20 knots or SE at 20 knots), and transit direction (inbound or outbound). The environmental conditions for the transits changed so that the worst credible conditions of wind and current were associated with the respective inbound or outbound transit.

Two ships were simulated for the tests. The container ship was 950 feet in length, 106 feet in beam, and had a draft of 36 feet. The tanker was 894 feet in length, 106 feet in beam, and had a draft of 42 feet.

The transits were made in the existing channel configurations as well as in the planned configurations. This is done in typical port design studies since absolute measures of performance for safe navigability in a channel have not been established. The existing channel condition therefore becomes a baseline and represents a standard against which the proposed channel modifications can be tested and compared. Pilot performance can be measured in terms of: swept path, closest point of approach, and reserve control authority (i.e. engine, rudder, and tug power remaining). If the tests of the planned channels do not reveal a degradation in these measures as compared with the same measures made when the pilots transited the existing, baseline channels, then it may be inferred that
the planned channels have, at least, the same navigability as the existing channels.

The container ship was used to test the channels' widths. It was longer overall and was more sensitive to the wind. The tanker tested the channels' depths. It was deeper and was more sensitive to the current. Both ships were assisted by tugs, the placement and use of which were dictated by the test pilots. The number of tugs and available horsepower, however, remained identical for each run.

Test results
Without referring to the actual quantitative analysis of the data collected during the on-line runs, it is sufficient for the purposes of this paper to summarize the findings. In general, the final report stated that the proposed improvements caused no degradation of the existing navigation conditions. Referring again to Figure 3, the more specific results were as follows:

- **Gulfport**
  Inbound tanker transits were accomplished with the same difficulty experienced in the existing channel with lesser drafts.

- **Elizabethport**
  Inbound tanker transits showed no significant difference in navigation conditions between the proposed and baseline conditions. Both inbound tanker and container transits support the value of the widening along the southern channel boundary at the northern end of Howland Hook.

- **Shooters Island**
  For inbound transits the modified channel condition improved all passing situations north of Shooters Island.

- **Newark Bay and Bergen Point to Bayonne Bridge**
  For all inbound transits there was no degradation in the navigability for the proposed channel. The tests revealed, however, that the widening of the turn at Bergen Point provided no advantage to typical pilot maneuvers. For the outbound transits there was an advantage noted with the widening along the western bank at the entrance to Newark Bay, but, again, the widening at Bergen Point gave no significant advantage.

Conceptual change
With the publishing of the final report and the fact that the simulation study did not indicate reason to modify the engineering design to maintain navigability, the issue of testing the port design in these channels should have come to an end. However, that was not the end of the matter. Some of
these same channels were studied again, several times, and it is this revisiting of the area that gives evidence of a conceptual change brought about by the existence of a ship simulation technology.

Phased construction testing
The Kill van Kull waterway and entrance into Newark Bay is of vital importance to the well being of the port of New York-New Jersey. If that waterway were to be closed down, the traffic in port would be reduced to a virtual standstill. Yet, plans had been made to dredge the Kill van Kull channel. This dredging included the blasting and clearing of rock, and, by necessity, some portion of the channel would have to be closed. Not only would the channel be partially closed during construction, there would be increased risk of accident due to large ships transiting a waterway made more difficult by reduced channel breadth and the presence of dredges and their associated tugs and barges.

Because of the importance of the waterway, a phased construction plan was conceived. Phased construction would allow the work to proceed and, at the same time, allow large ships access to their berths via the same channel. The question which naturally arose was how the construction areas should be designed and in what sequence they should be worked on so that the channel would present as little risk as possible. The authorities involved, the Port of New York-New Jersey, the Corps of Engineers, and the Coast Guard's Captain of the Port, immediately recognized the value of applying ship simulation to this question.

In 1989 and again in 1991 the Port of New York-New Jersey contracted with the CAORF division of MarineSafety International to run simulation tests of the shape and size of channel constrictions which would take place during the construction of the improved Kill van Kull channel. The ship simulation study evaluated the navigability of interim navigation channel configurations designed to accommodate vessel traffic during excavation of the planned deepening of Kill van Kull. The excavation plans which were tested were developed by the New York District of the Corps of Engineers to allow for uninterrupted vessel traffic during the construction phases of the harbor improvement project. Tests were run more than once since each succeeding study demonstrated that there were potential problems with the planned channel constrictions. The plan had then to be changed, and the resulting plan tested. Figure 4 shows the original phased construction plan. The borders of each phase show how the channel would change during the construction of that phase.

Large container ships and large tankers will transit the channels while they are being improved. Consequently, it was necessary to test each phase of construction with both types of
FIGURE 4 - Original Phasing Scheme
vessels. The ships used in the previous simulation study were chosen once again because they are representative of the largest vessels that will transit the area during construction.

Basic Study
Four New York pilots/docking masters participated in the phased construction studies. There were actually three separate studies run. The first, or Basic Study tested all the phases of construction. Following this study, the Optional Study was performed to examine recommended changes resulting from the Basic Study. Finally, after the phased construction plans had been re-formulated, a third study was performed to test one critical area of those final construction plans.

The Basic study simulations were conducted, and navigation safety problems were found to exist in the original construction phasing scheme. The Basic Study, therefore, yielded recommendations in the form of mitigation measures to be tested and validated in the Optional Study. Operational guidelines and recommendations for vessel operations during all phases of construction were also recommended.

Guided by the Basic Study findings, the New York District of the Corps of Engineers developed a revised phased construction plan. The new plan revised Phases 3 and 5 to directly address the navigation problems encountered. The revised phases of construction were then tested during the Optional Study.

Optional Study
The Optional Study simulation tests revealed that the revised channel layouts mitigated some of the problems identified by the Basic Study; however, the mitigation was not sufficient to permit unrestricted large deep-draft ship transits during construction. The following operational restrictions were then recommended:

1. Allow only one way traffic in and around restricted areas during all phases of construction.

2. Restrict the movement of wind sensitive vessels during periods of high winds during all phases of construction.

3. Require additional tug support during construction Phases 3, 4, and 5.

4. Restrict the movement of vessels to the time at or near slack water during Phase 5, taking into account that a fair tide is the more critical situation.

These recommended operational guidelines were then used by the Coast Guard as the basis for a proposed rulemaking of a Regulated Navigation Area during actual construction.
Acceptance Area J Study

Figure 5 shows the construction phases as designed after the Basic Study described above. Notice that the various phases are now called Acceptance Areas. Also notice that the operational restrictions outlined above for the most part involved Acceptance Area J. It was decided after discussions between MSI, the Corps of Engineers, and the Port that further analysis of vessel navigation during excavation of Acceptance Area J could lead to the identification of conditions wherein some of the operational restrictions indentified for Acceptance Area J could be eased.

This third study of the process of construction had three basic objectives. First, the study was to identify the portion of Acceptance Area J that was most restrictive to navigation. Second, the study was to ascertain if vessels smaller than those originally tested could safely transit the area during excavation of Area J. Third, the study was to more thoroughly investigate the effect of current and wind velocity on navigational safety since the previous analyses had focused only on the maximum credible adverse conditions of current and wind.

Four New York pilots participated in the study. They piloted four different size ships through the design area. Two of the ships were the same as those used in the earlier tests. The other two were smaller ships of the same type. The smaller ships had the following characteristics:

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<thead>
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<th>Container ship</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length over all</td>
<td>725</td>
</tr>
<tr>
<td>Beam</td>
<td>95</td>
</tr>
<tr>
<td>Draft</td>
<td>32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tanker</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length over all</td>
<td>612</td>
</tr>
<tr>
<td>Beam</td>
<td>85</td>
</tr>
<tr>
<td>Draft</td>
<td>37</td>
</tr>
</tbody>
</table>

These smaller ships represented most of the ship transits made through the Kill van Kull area in the year the study was conducted. They therefore also represented the ship type that would probably be running through the area during construction.

The earlier studies stressed the maximum credible adverse conditions. During the Area J study the velocity of the flood and the ebb currents were halved. The wind velocities were reduced to 10 knots from the northwest and to 10 and 15 knots from the southwest. Light air conditions and slack water conditions were also tested.
FIGURE 5 - Kill Van Kull/Newark Bay Channel Improvements
The approach to testing in this later program was to configure each successive test based on what had been learned from previous test runs. The simulator was used in an interactive problem solving mode wherein test parameters were systematically investigated by the pilot incorporating their appropriate real-world background. Each pilot performed test runs on the vessels that they were most likely to handle in the real-world with the test conditions selected and refined in consultation with MSI and representatives of the Port and Coast Guard.

The analysis of the tests produced the following operational recommendations for the phased construction:

1. Operational guidelines for large deep-draft vessels prescribed for Area J in the earlier study can be alleviated substantially by dividing that area into two areas.

2. Vessels 750 feet or less in length can transit in the vicinity of the two J areas without operational restrictions.

3. Transit restrictions during excavation of J-East should be imposed on large wind sensitive ships when wind speeds in the Bergen Point area exceed a sustained 15 knots.

4. To reduce the time the above restrictions will have to be in place, area J-East should be constructed first and opened to vessel traffic soonest.

This description of the phased construction study was made to illustrate from the area of port design studies that ship simulation has achieved a recognizable level of maturity, equal to that of other system technologies. The existence of real-time, full mission ship simulation itself suggested an application not previously indicated before the technology was fully developed; that is, that the sequence of channel construction could be examined in detail. This examination provided information which will allow the Kill van Kull waterway to remain open and safe during channel construction.

Conclusion

The examples of ship simulators being used for training and for port design demonstrate how vital ship simulation technology as become to the maritime industry. The examples also show that the marine industry is itself realizing applications of the technology not conceived during its formative period. These points plus the conceptual changes illustrated in the examples toward maritime training and port design give evidence to the thesis that ship simulation has reached a mature stage.
This, of course, does not mean that ship simulation has achieved all that it can, or that there are not areas that can be improved. It means, rather, that the technology has become a vital part of the full realm of the maritime industry.
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The role of simulators in nautical training and research

H.G. Blaauw

This paper provides an overview of the role of simulators in nautical training and research.

Several developments in the shipping industry lead to an increased need for training. In the present paper a distinction is made between technical and non-technical training. Both types of training are required to meet the present and future demands of the shipping industry.

Research, in which simulation models play a dominant role, is needed to guide technological developments, like the concentration of information and various tasks on the ship's bridge.

The concern with the environment in relation to the transport of dangerous goods and the risk of pollution requires careful planning and monitoring of traffic flows.

The design and modification of ports determine the need for research and evaluation instruments in which nautical safety and efficiency are key concepts.

These factors lead to design criteria for nautical simulators and simulation models which are indispensable tools and cannot be missed anymore to solve the various research and training problems faced by the shipping industry.

1. Introduction

Bridges of modern ships tend to be equipped with more instruments and information systems. The following distinctive parts are of importance:

* Navigation instruments;
* Communication, including information on weather and waves;
* Propulsion systems;
* Manoeuvring devices such as bow thrusters and steering engines;
* Cargo handling and monitoring systems;
* Monitoring systems of engine performance and hull.

The reasons for this increase in functions on the bridge are the present requirements for efficiency and safety. To reduce the cost of exploitation the number of crew members has been decreasing steadily and serious attempts were and are made to reduce the cost of maintenance and to minimize the working expenses, however, without reducing the safety of crew, ship and cargo.

Examples to the above are the availability of good navigation instruments to avoid unwanted deviations from the required track, to create the possibility of efficient weather routing and the introduction of sufficient manoeuvring capacity to reduce tug assistance. Moreover, there is a tendency to transfer information of the engineroom to the bridge so that watch keeping during the nights in the engine room can be avoided. The cargo has to be loaded and unloaded efficiently and, in many cases, is monitored during the voyage to guarantee that the cargo is in good shape upon arrival. Hull monitoring can be of utmost importance as recent history with bulk carriers shows.

The introduction of these functions on the bridge generates new categories of problems. For instance, given the fact that a lot of different information is presented on the bridge, this information should not only be processed during normal operational conditions but also during stress situations. This implies that the information should be presented such that in a very short time a good impression of the whole situation can be obtained followed by the right sequence of actions.

In addition bridges are getting more and more complex, hence the familiarization time for new officers on board does increases considerably.
Now, because of the decrease in operational sailing time of the crews, the possibility of getting training on board, the fact that more and more of the crews are composed of seaman of different nationalities as well as the increase of bridge functions, simulator training provides a good instrument to keep up the required safety and efficiency level. This simulator training can be supported by PC oriented courseware to train specific tasks of the ship's operation or specific aspects for instance to reduce the familiarization time.

By means of simulator training the skill to manoeuvre ships safely given the specific environmental conditions can be improved and maintained. In this respect procedures are essential. Moreover, the way in which the information is presented and subsequently processed can be trained.

Partly away from the simulator, attention can be paid to bridge management training to deal with team building of the bridge officers in which the role of the pilot may be included.

Except for the shipping companies also the authorities responsible for the infrastructure have a thorough interest in safety and efficiency of navigation.

On the one hand a well designed and efficient infrastructure contributes to the economy of a country and is therefore of great importance. On the other hand a keen eye has to be kept on the environment. Risks of polluting the environment and disturbing existing ecosystems should be kept as small as possible.

Looking at the infrastructure first, the dimensions should be such that all ship manoeuvres involved can be executed safely. The definition of admission criteria deserves special attention. Also motivated answers are required when shipping companies ask permission to enter and leave ports without assistance of pilots.

When designing new ports or improving existing ones a nautical check on a simulator is usually carried out to determine whether the design meets the required safety level or to provide answers on other relevant questions such as the contribution of aids to navigation to safety.

When more shipping operations and other water related activities take place, for instance offshore activities, the interaction of traffic and traffic with structures is becoming relevant.

In the first place the vessel traffic operations should be mentioned. Along the coast and rivers of the Netherlands the nautical Vessel Traffic Service (VTS) operators are active. They highly contribute to the safety of navigation. Training of these VTS-operators takes place at a dedicated simulator.

To study the traffic process, the related safety level and to be able to predict the safety level of future situations use is made of traffic models. These models are becoming powerful tools for the authorities for planning purposes regarding the development of future infrastructure and for improving the existing safety level. To calibrate these traffic models use is made of extensive accident databases.

Based on these database studies are carried out to assess e.g. the effect of traffic separation schemes and the effects of planned offshore operations.

Training and research impose conditions on both the architecture and layout of nautical simulators. Flexibility both in hard and software as well as in efficient maintenance are key words in this respect.

At MSCN in Wageningen attention is paid to many aspects related to efficient and safe navigation. The company is a joint venture of MARIN (Wageningen) and Delft Hydraulics and has become operational early 1992. In the following chapters a state-of-the-art of the MSCN activities is presented.
2. Training

2.1. Introduction
In the Introduction, several reasons for training are indicated. Although the nautical industry knows the phenomenon of training on simulators for quite a long time, systematic and structured simulator training design is a relatively new development. Looking at simulator training with educational technological "glasses", one of the first questions that must be answered is:

Are training simulators effectively being used?

This is a very interesting question which often must be answered with "no". MSCN has started the design and development of new training programmes aiming at using the simulator as effectively as possible.

2.2. A structured approach to training design
The field of simulation has attained a sophisticated state as a result of the capability to reproduce high-quality, realistic visual, aural and tactile phenomena. However, this capability has given many individuals in the training profession a false sense of security because it has been assumed that by merely exposing the trainee to a group of high fidelity simulator events and conditions from the real world, effective training will take place. Such an assumption, however, does not always hold. Very often, too little emphasis is placed on specific training criteria. Little is known about what specific demands a training simulator imposes on training and training design. The effectiveness of training is much depending to a large extent on the skills of the instructor. What is missing is a systematic, structured approach to training.

MSCN has based its systematic training design and development on "Designing Instructional Systems" (ISD) of A.J. Romiszowski [1]. One of the first steps in this approach is a thorough task analysis which must map the tasks, subtasks and the underlying knowledge and skills to be trained. On basis of the results of this analysis, the following aspects can be determined:

- what exactly must be trained on the simulator;
- the operational sequence of the tasks;
- the evaluation criteria;
- the kind of knowledge and skills;
- the applicable instructional tactics.

This information, resulting in detailed learning objectives form the foundation of further training development.

The next steps deal with the design of the training scenarios. Together with these scenario's, MSCN is developing:

- especially designed instructional tactics (in cooperation with the Department of Education of the University of Twente);
- a training evaluation system which must be able to determine if and how the training programme has contributed to the improvement of the knowledge and skills of the trainee. From the results derived from this system, it will be possible to determine where improvements of the training programme are required;
- entrance level and exit level tests.

2.3. Training modules
The above mentioned facts must result in several series of training modules (see figure 1). In these modules, the established basis formed by the results of the task analysis, is clear. From this basis one or more standard training scenarios are developed. However, it is possible to adapt these standard scenarios according to specific wishes of the customer, the target group characteristics or events during the training session itself.

Anticipating on possible variations, the training module gives some indications and directives. The simulator must be easily adaptable to new situations, so that possible customer demands of the client can be quickly incorporated into the system.

The training evaluation instrument controls all aspects of the modules checking for possible improvements.
MSCN is using training materials of the flight crew training centre of KLM Royal Dutch Airlines thereby benefitting from their large experience in simulator training.

**Figure 1: A training module**

2.4. "Technical" training

MSCN is currently developing the following three types of "technical" training:

1. **Skill training** aiming at specific skills like the mooring of a ferry in various difficult situations. Within this kind of training also part task simulators will or can be used for example to practice the engine room monitoring or cargo handling tasks before going to the full mission simulator. It is also possible to integrate Computer Assisted Instruction (CAI) in these part task simulators so it will be possible for one instructor to individualize and differentiate individual training.

2. **Procedure training** aiming at required bridge procedures for various situations;

3. **Familiarisation training** aiming at the transition to another type of ship and/or modified part.

2.5. "Non technical" training

Except for the above mentioned types of training, MSCN will also develop two "non technical" training courses:

1. **Instructor training**;

2. **Bridge management training**.

MSCN is of the opinion that simulator instructors must have a close relation to practice. They have up to date information available which they can pass to the trainees and this will make the level of acceptance of the instructor by the trainees higher. But a good pilot or bridge officer is not necessarily a good instructor. For that reason selected pilots and bridge officers are given a course on instruction methods after which they can be employed by MSCN when necessary. Because of the fact that these "MSCN instructors" will not use the simulator frequently, the instructor facilities of the simulator must be user friendly. Training scenarios must be easily adaptable before and during the training so that the instructors will have total control over the training. Also the total simulator system must be robust enough to tolerate input mistakes both from the instructor and the trainees.

The development of the bridge management training is due to the need for more management skills by bridge officers because of the increasing "mixing" of the bridge teams in culture and level of education.
The training will aim at for example: decision making, giving and handling of feedback and information processing and leadership styles. In the airliner industry, the significance of this type of training is growing rapidly.

3. Research with manoeuvring simulators

3.1 Introduction

Research with the aid of manoeuvring simulators can be performed for two totally different purposes, namely:
- Ship design;
- Harbour and fairway design.

Each purpose has its own requirements, but the starting points are the same. Both purposes will be discussed in this paper.

3.2 Simulator research for ship design

As already mentioned in the introduction two items are of interest within ship design. The first item is related to the performance of the vessel that is it's capability to perform a certain mission. The second item is directly related to the information transfer between the vessel control system and the navigator. These items will be discussed separately bearing in mind that they are interacting.

For certain types of vessels the importance of manoeuvring performance is steadily growing. For instance, the increase in size of luxury cruise vessels in combination with the requirement to call at small picturesque harbours in the Caribbean puts more stress on the manoeuvring performance. The size of ferries is often increased without increasing the size of the harbour facilities.

Offshore operations require vessels with good station keeping performances. Special rudders, bow thrusters and controllable pitch propellers in combination with an integrating controller must result in an optimal controllability of the vessel. But before the actual vessel is built simulator studies should prove that the proposed tools are sufficient. Vessel operations are simulated under various environmental conditions. Limiting conditions are determined up to which safe operations are possible. When these conditions are exceeded procedures have to be defined such as which measures have to be taken to cope with these extreme conditions.

An example of a study which combined both channel design and ship design is the study executed by MARIN for the Carnival Cruise Lines ship owner. Problem here was the entrance and departure manoeuvre of Freeport with the huge newly-built cruise liner 'Fantasy'. The entrance and turning basin at Freeport was regarded as 'narrow' by the masters of visiting cruise liners. It was expected to become crucial for the 'Fantasy'.

Full mission simulation was carried out with this vessel. Several environmental conditions were investigated and a separate programme was executed with an integrated joystick manoeuvring device in order to compare the performance of this system with that of manual control of main propulsion, rudders, bow and stern thrusters.

The project resulted in recommendations (which are implemented now) for widening the approach channel and the modification of manoeuvring strategies. The joystick control appeared to improve the manoeuvre, especially within the turning basin.

A completely different aspect of ship design is the bridge layout and the presentation of all sorts of information to the navigator. The amount of information available on the ship's bridge is still increasing. Among other things information is provided on position, weather forecasts, route planning, cargo handling, stability and engine performance. Furthermore there is more communication i.e. with other vessels, with the shipping company and with traffic control centres. In principle this increase in information and communication reduces the risks of navigation and is therefore also often an argument to reduce fairway dimensions, to reduce the crew and even to allow an increase in traffic intensity while maintaining the same safety level. But there is still one man on the bridge who is actually sailing the vessel. He has to interpret all available information and must take decisions.
An optimal bridge layout with an optimal positioning of controls, radar screens and computer screens is a first step to make the information better available to the navigator. But the amount of data available on the bridge is still increasing and new tools are required to monitor the available information and select and display what is really required. A decision support system should select the critical information for the navigator and present it logically. The next step is that such a system interprets the incoming information and advises the navigator. For some matters like weather routing, optimising fuel consumption or stability these systems are available but they are not yet integrated into one system. For navigation in confined waters, including the effect of other traffic, such a system is even far more complicated.

Such a decision support system will be one of the most important topics in nautical research for the next few years.

For the design, implementation and verification of such a system nautical simulators are an indispensable tool.

3.3 Simulator research for harbour and fairway design
In most harbours and waterways there is still an increase in cargo flow. This also implies that the density of traffic and also the average ship size is increasing. Furthermore it is a well known fact that the amount of hazardous cargo being transported is also still increasing. In general one can say that the safety level of cargo transportation like rail and road. But still, if something happens the consequences may be disastrous.

Within the development of ports and fairways main questions are:
- what is the maximum ship size?
- under which condition is safe passage possible?
- what is the determinative traffic situation?
- what is the safety level of the harbour?

Nowadays we see that larger ships and more ships are allowed in relatively narrow fairways. The argumentation to allow this is the availability of more electronic equipment like:
- Vessel traffic systems;
- Better positioning systems (GPS);
- More knowledge about the actual environmental conditions during transit.

All this information offers the opportunity to schedule more exactly entry and departure manoeuvres. Despite all this information, the actual manoeuvring in busy areas or confined waters is still performed by the navigator. He has to absorb all available information, draw conclusions and take decisions.

Much more stress is put on the man on the bridge. More and more he becomes a critical factor in the navigation process. Consequently a failure or accident is often caused by the "human navigator". To determine the risk of "failure", simulation is the only tool which can be used to estimate the potential risk of certain manoeuvres. Such a simulation should have the possibility to include other traffic and a vessel traffic system.

For the statistical analysis of simulated manoeuvres various methods are available, each with its own potential and drawbacks. Some methods have proven to be useful for the comparison of conditions, like the method proposed by Van der Beek [2]. New promising statistical methods are still under development, for instance the method proposed by Kok and Burgers [3].

Another approach of the problem how to determine the safety of channel passages is the method of pairwise comparison (Cook [4]). This method compares the results of simulator runs with existing situations with a known safety level. After a simulator run the pilots are confronted with questions like: "Is passage under condition "1" more difficult than under condition "j"?"? The results of these questions are analyzed such that inconsistencies are detected.
Furthermore, a coefficient of agreement is determined which is a measure of agreement between the experts within the experiment, and a so named "goodness of fit" which, in practice, indicates whether the modelling assumptions are valid. To obtain balanced conclusions from simulator research information from different sources e.g. statistical information and expert opinions, have to be combined into a unifying framework.

4. Nautical Safety Assessment

Safety and Efficiency must be kept in balance with each other in the strategic and operational evaluation of nautical problems. This balance is continuously changing by governmental decisions that hence classification societies by putting heavier weights on the safety side of this balance. All this makes the accurate assessment of safety in a wider range of areas necessary and more important every day. The mutual effects of safety on efficiency adds to the necessity of an accurate assessment as well.

4.1 Safety assessment methods

The existing methods are all based to a certain level on the modelling of aspects of the nautical problem area under investigation. The choice of the level of modelling is firstly determined by the state of the art of the available techniques where Albert Einstein, although not being a nautical expert in particular, gave us our leading principle: "As simple as possible .... but not simpler". Secondly, the type of the problem under investigation determines the choice of the method. For example, if the number of ships involved is substantial then the traffic density parameter enters the scene and will change the applied method completely.

The differences in approach then, can be distinguished by the measure of modelling used in the safety assessment method. On the one end of the scale we have the full mission simulator used in multi-ship situations and on the other end of the scale the mere registration of accidents in the form of casuistries and statistics in case that fleets of ships are involved. In the last case statistical data helps us where modelling of the total process would be cumbersome. However if predictions on the safety level of future traffic situations have to be supplied, based on this historical data some modelling assumptions have to be introduced. In between these two extremes, traffic simulation further helps to relate the historical accidents data to traffic density and fairway dimensions by relating the traffic and its manoeuvring characteristics to probabilities of accidents.

In the refinement of the traffic simulation models, aiming at a better description of the behaviour of the individual ship in the fleet, again the full mission simulator is used. It contributes by showing nautical experts typical traffic situations on which they give comment, which is used for setting rules governing traffic flows in the traffic simulation models. The usage of this model for determining safety of the design of an inland waterway is currently in progress.

Traffic simulation or assumptions on traffic densities are used for the determination of probabilities of accidents in relation to offshore installations as well by using historical accident data.

4.2 Vessel Traffic Services

Risk assessment methods based on historical data or on traffic simulation can also be used in the evaluation of newly designed VTS scenarios for sea areas under consideration. A cost benefit analysis should determine the appropriate level of VTS support in terms of safety and efficiency. Such a cost benefit analysis has to include both costs of the VTS system and the reduction in risks and waiting time.
5. Development of nautical simulators

5.1 Introduction
The Ship Maneuvering Simulator System of MSCN is designed to meet the requirements of ship officers, pilots and nautical students to gain or to augment their understanding of the behaviour of ships, the effect of external conditions such as wind, waves, current and shallow water, how to deal with tugs, how to control the computerized systems and how to act in case of emergency situations. Furthermore the Simulator System is designed for application in consultancy projects where design of ports and fairways and nautical safety play an important role.

The Simulator System is capable of simulating up to 10 fully controllable ships, each equipped with a sophisticated CGI (Computer Generated Image) system with a 360 degrees horizontal angle of view.

Due to the modular set-up and the scalability of the system it can be adapted to any specific training- or research project requirements and available budget. Future upgrades are always possible by simply adding components, hardware or software without major adaptations to the original system.

5.2 Requirements
In designing the Simulator System the following design requirements have been followed:
- modularity;
- scalability;
- flexibility;
- robustness;
- real world bridge;
- high performance outside view;
- part task possibilities;

These requirements are reflected in the set-up of the Ship Simulator System.

5.3 Set-up of simulator system

5.3.1 General
The Simulator System consists of a real time part, the Simulator part, and three non real time parts namely, Preparation, Debriefing and Analysis. It can be regarded as a collection of different functional components, referred to as sub-systems. Each sub-system, in turn, can be considered as a logical unit that fulfills a number of functionally related tasks. Sub-systems can be built up from hardware, from software or from a combination of the two. Sub-systems are connected via LAN communication networks. The software has been developed in an Ada Programming Language environment making use of Object-Oriented Design techniques. The latter technique allows a reflecting of real world objects into recognisable objects in the software and hardware.

![Diagram of Simulator set-up](image)

5.3.2 Sub-systems
The Instructor Sub-system enables the controlling of the simulation process by an instructor. Once a specific project and condition have been selected, the instructor can for instance start and halt the simulation process and reposition and playback a previous carried out simulation run.
The Ship Sub-system

Within the Simulator Systems ships are defined into three different classes: Own Ships, Targets and Tugs. The main objective of a Simulator System is to simulate the behaviour of the Own Ship which must be identical to that of a comparable real ship. This is achieved by the use of extensive mathematical models which describe the ship's behaviour. The more accurate the mathematical models are, the more realistic the simulated ships behaviour is in the Simulator System. Own Ships are extensively modelled and are being controlled by humans.

Own Ships are ships with extensive sub component modelling and always consist of the following major sub components: AUTCON which models the functions of the various autopilots, ENGINEROOM which delivers the actual control settings and MATMOD (mathematical model) which generates positions, orientation angles and velocities;

The modularity of Own ship is very clearly reflected in the software. Each force acting on the ship is modelled as a separate Ada package. An Ada package consists of a specification part and a body. The specification part is always resident.

The Bridge Sub-system

The Bridge Sub-system resembles the bridge of a real ship and provides the manual control functions. It consists of a number of consoles with instruments which are connected through a front-end computer, with the other parts of the system.

As a consequence of the modular set-up the bridge of the Simulator System can represent a wide variety of ships. It is possible to rearrange the consoles as well as the instruments in the consoles in a very short time. Instruments are mounted in sub-panels with standard dimensions and can be plugged in anywhere in the console. A software configuration file keeps track of the position of the instruments and sends the right data to the right port.

The Outside View Sub-system

Together with the Bridge Sub-system the Outside View Sub-system is very much responsible for the realistic feeling the simulator system evokes. The Outside View Sub-system presents the scenery in which the ship, controlled by the crew or a single person sails. It generates in real-time the actual visual image, covering a total viewing angle of 360 degrees.

The scenery is generated by dedicated high-performance graphical computers with special three-dimensional visualisation software components. The image is built up of different sectors of about 36 degrees. Each sector consists of one graphical computer and one projector. The size of the image is scalable between 1 and 10 sectors.

Radar Sub-system

On bridges of modern ships rasterscan radars are most commonly used. The Simulator System is equipped with one or two rasterscan radars which were built by MSCN.

The Radar Sub system includes ARPA functions and is in accordance with the requirements imposed by IMO.

Special Effects Sub-system

The Special Effects Sub-system offers a wide range of utilities which support the main functions of the Simulator System and increase the real world effect. Some of the utilities, presently available are: sound generation, special dynamic effects and NAVLAB to train the use of navigation instruments.

5.4 MSCN Simulator Systems Series

MSCN offers a wide range of Simulator Systems which may vary both in size and application; for instance the MERMAID 100, MERMAID 500 and MERMAID 900 series. The MERMAID 100 is a relatively small simulator setup with a small bridge mock-up and a reduced set of available operations whereas, the MERMAID 500 is a full-mission ship manoeuvring simulator with extended outside view capabilities and all possible bridge features.
In addition to the MERMAID 500 the MERMAID 900 series offers a fully integrated Engine room simulator, capable of training of Engineroom Staff.

Furthermore, MSCN has developed part-task simulator systems which allow stand-alone operations of specific tasks. These part task simulators run on relatively small computer systems such as work stations and top of the line PC-stations.

Acknowledgement:
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The human factor in ship handling and its effects on marine safety and the environment

J.J. Mol

Abstract.

Shipowners and shipmasters are under a great pressure to avoid casualties in general and particularly accidents that affect the marine environment. Much is done in the way of prevention to reduce the risks of casualties and claims. Shipping is an international activity and therefore national and international organizations are involved in marine safety.

In spite of all efforts, including the availability of high quality ships, equipment and modern training systems, collisions and groundings take place worldwide nearly every day. The daily casualty report in Lloyd's List contains all maritime casualties of any significance. These accidents may cause pollution and they are often the result of poor navigation and shiphandling practices. In order to avoid maritime disasters as they have occurred in the past few years, it is essential to improve the proficiency in navigation and shiphandling of certain navigators with emphasis on the planning aspects and a proper control of the execution of various actions.

International standards.

International safety standards have been set by the IMO, the agency of the United Nations in charge of marine safety. Consultative to IMO are a number of maritime organizations such as the Shipowners Association of Latin America, ALAMAR, and IMPA, the International Maritime Pilots' Association. Recommendations made by the IMO are often incorporated in the national law and regulations of its member states. However, these IMO standards should be considered as minimum standards. National maritime authorities and organizations have their own responsibilities in this respect. This also applies to shipowners and pilot services. Each particular coastal area, fairway and port presents its own degree of risk to navigation.
and safety standards should be in accordance with the requirements for such an area open to navigation. With respect to the navigational and shiphandling skills of navigators, shipmasters and pilots alike, the safety factor not only depends on the knowledge and experience of the navigator but also on the application of that skill at the right moment in a particular situation.

**Skill, ignorance and negligence in shiphandling.**

Skill in navigation and shiphandling commonly includes knowledge and experience. The degree of knowledge depends on the level of education, training and the results of proficiency tests. Basic knowledge of shiphandling may be learned from textbooks and from simulator courses even before any shipboard practice has been gathered. Experience in navigational matters and ship handling is gained on board of ships. This process is different in the various trades and types of ships. There is a clear distinction between deepsea navigation and coastal navigation with ocean going vessels, coasters and ferries. Ocean navigation and shiphandling is outside the scope of this survey, which is limited to coastal areas, fairways and port areas.

A person on a ship in charge of navigation and shiphandling should not only have sufficient skill to control a ship in a certain situation, he should also have enough initiative to apply his skill whenever needed. It implies to be alert and prepared for the unexpected and to act with determination, confident that a certain action or manoeuvre will have the desired result. Such competence is certainly required for the persons who are manoeuvring ships in restricted areas including anchorages and inland waters. Usually the shipmaster or pilot is in charge of navigation and shiphandling in those circumstances. Marine accidents, particularly collisions and groundings, may be the result of bad luck or misunderstandings, but other reasons could be ignorance, negligence or criminal behaviour. Ignorance in shiphandling may include a lack of knowledge in the proper use and interpretation of nautical instruments or poor communication practices. Negligence, a lack of proper care, may be a temporary or permanent attitude of certain navigators. It could be related to their educational, social or cultural background or poor management as a whole. Some examples of negligent behaviour: omission of testing
procedures of navigational instruments, omission of the testing of astern power of ship's diesel engine if doubtful before entering a sensitive manoeuvring area, unattended anchors while proceeding in port areas. Criminal behaviour will be evident in those situations when navigators and shiphandlers are not capable any more to operate properly because of their physical condition which may range from fatigue to drunkenness and the influence of medicines and drugs. These are social and management problems which may remain unknown until a serious accident has happened.

Critical situations that may arise in coastal areas, port approaches and anchorages.

Serious accidents with ships and consequent oil spills have taken place in the approach areas to certain ports, often as a result of a grounding or touching of the seabed by ship's hull. Usually these casualties occur when there is no pilot on board of the ship in question. Therefore a report of the accident to the authorities will be delayed or omitted. The necessary rescue and cleaning operations would start then much later which is a great disadvantage. The causes of such accidents, including collisions, are various. A number of those cases have been the result of poor ship handling and anchoring practices. Some notorious casualties in the past were the loss of the large low-powered bulkcarrier "Hyundai New World" in Ponta da Madeira, Brazil in 1985 and a few years later the catastrophe with the tanker "Exxon Valdez" in Alaska. Both ships were fully loaded. Misjudgement of the turning capacity of the vessels, a common human error, resulted in a total loss of the bulkcarrier and her cargo and an enormous oil spill caused by the tanker. Bulkcarrier groundings have been reported in different parts of the world until this very year. In February 1992 the capesize bulkcarrier "Arisan", 20 years old, grounded on the rocky coast of Norway after she had left the port of Narvik loaded with iron ore. The result of this was a serious oil spill and pollution of the coast through the damaged fuel tanks. The probable cause of this accident was engine trouble in connection with risky anchoring practice. Engine problems with older ships are a threat to marine safety. Following this accident with the "Arisan" the Norwegian government has increased surveillance along the coast and also extended compulsory pilotage for certain ships. The nature of the coast, rock or sand and mud, certainly determines to some extent the degree of risk in case
of a grounding.

Surveillance systems and pilotage.

Loss prevention is a major task of shipowners, shipmasters, pilots and the maritime authorities. Independent observers and expert shiphandlers like marine pilots are important tools in the field of loss prevention. VTS-systems to guide the flow of marine traffic have also a controlling and informative task, in the way of safety and prevention. Marine pilots, operating on board of ships in coastal and inland waters are of great importance with regard to marine safety for a number of reasons. Marine pilotage can be divided in different specialities such as deep sea and coastal pilotage, port approach and river pilotage and also harbour and dock pilotage. A pilot may operate in one or all of these areas, depending on his abilities and flexibility in view of the needs for flexible pilots in certain pilotage areas. Whatever their working area may be, all pilots serve a common purpose which is safety. Another advantage for shipowners, charterers and the ports is timesaving when ships are guided by pilots because of their professional skills, including expert shiphandling and local knowledge. A main advantage of a pilot on a bridge of a ship is merely his presence as an independent observer and informant of what is good or wrong with the ship, her equipment, operational condition, command, crew, etc. In case of serious problems or risks he is the first representative of the port or national authority to inform shore stations immediately of his findings so that early and adequate measures can be taken to avoid accidents. A pilot is all eyes and ears when guiding a ship from A to B, positioned on ship's bridge as a spider in a web, also as an important link in communication between ship and shore, to other ships in the area and assisting tugs. Safety requires from pilots an excellent command of navigation and shiphandling of various types of ships including the use of anchors and tugboats, communication and procedures, and local regulations. Pilots often serve as interpreters in order to get things organized on board or to obtain the necessary information because of poor language skills of shipmasters and crew. Compulsary pilotage is also related to the vulnerability of certain areas open to navigation and the amount of risk that certain ships and ship's personnel cause to those areas.
Shiphandling training and the use of simulators.

The introduction of simulators for training in marine navigation started with the application of radar simulators. For over twenty years shiphandling simulators have now been used to train shipmasters, deck officers and pilots to improve their knowledge in ship manoeuvring, to refine or maintain the required skill and practice in the art of shiphandling. The shiphandling simulator has proven to be an excellent instrument to make navigators aware of the limitations of ships in the way of turning, stopping and control in general. It also gives the opportunity to navigators to rehearse emergency situations with ships like sudden engine problems. These training objectives are of great importance to prevent marine accidents and environmental damages.

Conclusion.

Marine casualties take place regularly and damages are sustained because of such accidents. Serious accident are certainly those that involve loss of life and those that affect the environment, the marine environment in particular. Human errors are often the cause of such accidents. Much is done to reduce the amount of serious accidents like groundings and collisions. In spite of all safety support measures in the way of the construction of efficient ships, the introduction of modern equipment and VTS-systems, adequate education and training, it is still the navigator on the bridge of a ship who, with his qualities and shortcomings, determines to a great extent the degree of safety that his ship carries along while proceeding in a certain navigational area. It is undeniable that good ships, modern equipment, surveillance systems and training facilities are indispensable to improve marine safety. However, these means are often not sufficient to avoid serious accidents with ships. Navigational errors and harmful conduct are also related to commitment, attitude, management, pay, addiction and fatigue of persons in charge of navigation and shiphandling. Particularly ships that are a potential risk because of cargo, fuel, ownerships and casualty records should be treated with great care by the maritime authorities in charge of navigation and safety. Additional expert manpower by skilled pilots and tug assistance when needed may avoid such disasters as reported on certain occasions in Lloyd's List. Mare liberum, the free sea, is for obvious reasons not so free anymore as it
was for centuries. Independent surveillance on board of certain ships in coastal waters and from shore stations will remain of interest for years to come. Marine pilots and VTS-operators have an important task in this respect. The contents of this account is a summary of the own experience of the author as a merchant officer, marine pilot and consultant, with assignments in various countries, in addition to publications in Lloyd's List the past few years.
Quality assurance in the shipping industry
R. Turner

Abstract
The paper reviews the growth of quality system implementation in the shipping industry since the early 1970's. The initial interest was focused on the new build aspect. This was developed successfully in Japan and later adopted by some European yards to improve their competitive position.

In the mid 1980's repair establishments started to show interest in quality systems although they faced different problems than those experienced in new construction. The most recent adoption of QA has emerged from the ship management sector of the industry.

Adoption of ISO 9000 requires in some instances supporting guidelines which assist in interpretation of the standard for a specific industry. Lack of uniformity in the guidelines produced by certification bodies has created a problem in itself. Some of the difficulties encountered during assessments are described although common problems across new build, repair and ship management are communication and document control, training and commitment.

Introduction
Within the shipping industry, the principles of quality assurance have gradually gained acceptance over a period of some twenty years. The initial interest commenced with the new construction sector in the early 1970's and much later spread into those organizations offering repair capabilities.

Certain recent events in the shipping world focused attention on the actual management of vessels particularly with respect to safety and pollution. This has created a further opportunity to use the management controls afforded by the implementation of the quality system standards in the ISO 9000 series.
QA in New Construction
Perhaps the most notable attempt to implement a quality management system approach to new build came in Japan in the early 1970's. With the introduction of the Very Large and Ultra Large Crude Carriers (VLCC's and ULCC's) the need to closely control and monitor the work flow became a critical aspect if delivery deadlines and product quality were to be achieved.

The problem facing those Japanese yards who were producing such vessels, many of which were 2.5 million tonnes dwt and larger, was the fabrication of some 135,000 tonnes of steel in a timescale of 40 to 50 working days.

Traditional inspection techniques had to be coordinated and precise build and inspection programmes had to be integrated into a closely controlled quality system. With the volume of material to be handled, the control of suppliers assumed a major importance as delays or late rejections would seriously influence the defined programmes. Supplier control coupled to Just In Time delivery was therefore essential.

The early quality programmes did not have the advantage of using ISO 9000 for their structure. However they effectively covered all the essential elements which are now taken for granted in any comprehensive quality system. There was still a heavy bias towards inspection, with three stage inspection being the general approach.

A number of the major Ship Classification Societies had recognized that they could take advantage of the quality systems being implemented by the shipyards to streamline their traditional inspection approach. By employing a blend of inspection and system audit the Classification Societies could still exercise their control over the process and at the same time obtain a greater insight into the company's operation.

Lloyd's Register of Shipping, the oldest Classification Society introduced its Hull Construction Scheme in 1973. Although the scheme did not cover all of the system elements now embodied in ISO 9001 requirements, it did have all the important features which would be expected in a comprehensive system, eg:

- process control
- calibration control
- design
- inspection and testing
- records
incoming material control
identification and traceability
fabrication control
sampling procedures
corrective action
control of non-conforming products

The first shipyard granted Lloyd's Register approval was NKK Tsurumi Shipyard in Japan followed quickly by 9 further Japanese yards. The move towards certification in yards outside of Japan was limited. In order to survive as international builders of merchant ship, a number of European yards progressively realigned their production controls and successfully implemented the requirements of the various Classification Societies with respect to quality systems. Under the Lloyd's Registers scheme, the first European yard to gain their approval was Odense Staalskibsvaerft A/S followed by yards in France, UK and Belgium.

With regard to the UK scene, those yards which had dealings with the Ministry of Defence warship programmes already had experience with management system evaluations. The MOD had introduced its own assessment standards - the 05 series - in the 1970's to control all of their suppliers. The standards were later to form the basis of the UK national standard BS 5750. This in turn was taken as the basic document for the development of the International Standard ISO 9000 series for the evaluation of management systems.

With the publication of the ISO 9000 standard in 1987, this generated in its wake a renewed surge of interest in system certification from shipbuilders. In the UK, LRQA acting in its capacity of a third party certification body was contracted to evaluate most of the major shipyards supplying to the merchant fleet.

The ISO 9000 requirements extended beyond those previously covered in the Classification Society schemes with stronger emphasis on written procedures, training, internal auditing etc.

Assessments undertaken by LRQA showed that almost one third of the requirements in ISO 9001 were cause for raising deficiency reports (non-compliance notes). In relationship to the clauses in ISO 9001, the following illustrates some of the problems encountered:
Quality System (4.2): This particular clause requires written procedures and work instructions throughout the organization. These have been lacking in many instances with a reluctance to commit working practices to paper.

Document Control (4.4): Generally there are a high number of documents in circulation eg. drawings, often with a short life expectancy. Control is recognized as being vital but difficult to implement. Work package systems, distributed and maintained at key work areas have gone a long way to improving the situation.

Purchasing (4.5): Many items are only purchased to satisfy a single contract and the control exercised over suppliers is often difficult. Past contract reviews are one means of establishing future supplier selection.

Process Control (4.6): Many shipyards and also manufacturers fail to realise that the following processes require qualification, testing of equipment and personnel evaluation.

- Welding
- Galvanizing
- Heat line bending
- Plating
- Painting, etc.

Inspection Equipment (4.10): The significance of calibration is not well understood. An effective system should strive to reduce the amount of calibration to the minimum yet still ensure that measuring equipment is suitable for the tasks performed. In some cases the cost of calibration may exceed the equipment cost and replacement may well be the most economic solution.
Internal Quality Audits (4.16): This feature is new to many yards where traditionally any form of audit or surveillance has been undertaken by the foreman. The findings are rarely formally reported and instant rectification on verbal instruction is the general practice with little chance of establishing the root cause of quality problems.

QA in Ship Repair
Unlike the new build environment where long term planning and programming is possible, the repair aspect presents a different set of circumstances. Speed of response can be of the essence if the trading capability of vessels and hence financial viability is to be maximized. Accommodating the element of speed to satisfy an owner creates difficulties when operating within a quality system designed to comply to the ISO 9000 series. Some of the problems facing repair yards are as follows:

Contract Review (4.3): This represents a main problem as contract review is generally done from verbal instructions or at best very limited written instructions ie. "recondition" "service" etc.

Process Control (4.9): There is often a lack of details available ie. no original drawings, specifications etc. Because of the need for rapid turn­round standard procedures are ignored.

Purchaser Supplied Product (4.7): It is generally overlooked that items provided for repair are customer supplied products. Items should not be scrapped without prior agreement.

Many of the problems associated with the repair aspect can be resolved by introducing a relatively simple documentation system. The question of contract review and process control can be handled by the yard giving confirmation to the customer as to their understanding and extent of repair. This can be transmitted to the process planning. Irrespective of the repair, certain tasks can be covered by general standing instructions, eg.

- weld repair
- cutting procedures
- line heating
Specific equipment strip down and maintenance can probably be handled by using manufacturers maintenance manuals.

**Ship Management and QA**

Although the principles of quality management systems have been readily adopted into the manufacturing industries, including the shipbuilding industry, the concept has now spread into the service sectors. Within the context of QA in service industries, the transport and distribution sector has certainly taken a positive move. This has been mainly orientated towards road transport, however over the last 18 months a great deal of interest has been created in the use of ISO 9000 in the activity of managing vessels.

The intention of using ISO 9000 in the service industry and particularly in the field of ship management has caused some organization to question its applicability. The general impression from certain quarters is that the standard was developed by engineers, for engineers and is applicable only to engineering activities.

The standard can be used over a very diverse spectrum of industry and this extends to the service sector. However what is required is a guidance document which interprets the ISO 9000 requirements in terms of the specific industry. This is the case with Ship Management if ISO 9002 is to be accepted as the appropriate assessment standard.

A complication which has arisen in the Ship Management sector has been the publication by the International Maritime Organization (IMO) of draft requirements IMO A647/16 relating to safety and pollution prevention. (This document has recently been revised to edition IMO A680/17). The document has many features which would be expected within any comprehensive quality system and has resulted in some certification bodies merging the requirements of ISO 9002 and IMO A647/16.

The ship management industry is now being confronted with a bewildering number of options with schemes ranging from ISO 9002 hybrids to those which are more strongly biased to the IMO draft requirements. Some of the options now available are:

- International Ship Managers Association Code (ISMA)
- DnV
- BVQI
- ABS
- LRQA Ltd
This can be regarded as the starting point of Ship Management schemes although it should be mentioned that a number of major operators already had implemented their own in-house systems. The code is extensive in its requirements and covers both shipboard and shore based activities. Certain demands of the code are outside of the ISO 9002 requirements eg. cost efficiency, insurance, accountancy. The actual process of auditing is undertaken as a joint arrangement between the three Ship Classification Societies who have been associated with the development of the Scheme.

The scheme was issued as DnV tentative rules for the "management of safe ship operation and pollution prevention". As with the ISMA code, the scheme covers both ship and shore activities and encompasses IMO 647/16 together with elements of ISO 9002.

The BV Scheme makes provision for shore/ship based activities and incorporates IMO 647/16 requirements and ISO 9002.

The ABS document on ship management issued in April 1991 requires compliance with ISO 9000 series and IMO 647/16.

The scheme developed by LRQA follows each clause of ISO 9002 and incorporates into the appropriate clauses the requirements of IMO 647/16.

In the early days of QA certification in the manufacturing industries, each certification body produced its own guideline to the assessment standard. This caused confusion because the final certification was to the appropriate National Standard eg. NEN 2642, BS B750 yet the guidelines had differences of approach.
This situation has now been repeated in the Ship Management field with equally confusing results. The solution which has gained ground in the manufacturing industry has been for the industry to develop suitable guidelines together with interested Certification Bodies. A good example of such an approach has been achieved in the Chemical Industry in UK. The time may come when the shipping industry, ie. the Ship Management element develop a similar approach. However because of the sensitive nature of preparing a unified guideline ie. it may influence the eventual classing of a fleet, then this may be a long term hope.

An important feature of the various ship management schemes is that they are voluntary and this has always been the case with third party QA certification. However there appears to be a mounting pressure to have mandatory certification regarding the ship management aspect and this is causing concern to certain operators, especially the smaller operators.

From the assessments undertaken by LRQA, certain features have consistently emerged regarding problem areas.

**Resources (4.1.2):**

Shore based office staff are usually quite limited in numbers and there is little resources remaining to take on the additional duties of the "quality/safety representatives. Invariably the appoint of such personnel leads to higher loading on the individual and the quality/safety aspect assume secondary priority. Similarly the resources available to develop and maintain the scheme are limited.

**Calibration (4.10):**

The calibration requirements of ISO 9002 cause grave problems. The degree of control used in manufacturing industry is misplaced in ship management. What has to be determined is precisely what instruments or equipment require to be calibrated eg. length, volume and weight measurements, navigation equipment, cargo monitoring instruments are typical. It is easy to impose extensive bureaucratic systems which have no positive and practical significance.
Internal Auditing (4.16) & Management Review (4.1.3): Although surveillance of the system may be undertaken it is often sporadic. There is no defined programme and little evidence available of it being undertaken. The management review often only consists of reviewing deficiency notes issued on the system without understanding the full extent of what the review should consider, eg.

- changes in trading conditions.
- Manning requirements.
- Suitability of the system to current operating needs.
- Analysis of complaints.
- Changes to company structure which have been or should be implemented.
- Defining quality improvement targets.
- Establishing and agreeing internal audit programmes.

Documentation (4.4): Because of the traditional nature of the industry, the documentation aspect as required by the ISO 9002 standard is usually quite vague or non-existent. Controlling the issue of documents has not been a strong feature in many of the systems examined.

Conclusion
The adoption and implementation of quality assurance techniques together with formal certification has been rather a slow process in the shipping industry. Logically the starting point was focused on new build although even in this area the adoption has not been widespread or particularly rapid.

Moving into the service sector of the industry has brought with it a degree of controversy with feelings running high amongst some of the shipping community.

Although it is possible to highlight specific problems under each category of the industry, ie. new construction, repair and ship management there are two problems common to all aspects:
Documentation: The most significant deficiency has been that related to documentation as this impacts on so many of the elements in the system.

A fundamental aspect of a quality system is good communication and a concise communication network must be established if the system is to be successful. The written word is a key feature and virtually every element of the assessment standard requires "written procedures" as it is recognized that verbal instructions can so easily be misunderstood or forgotten.

To be effective, instructions and procedures must be up to date and there must be a defined system to update documentation otherwise unauthorized practices quickly develop, product/service quality and productivity suffer.

Training: Throughout an organization problems can often be attributed to lack of knowledge as to what is expected. This indicates that one of the single most important factors in actually improving quality is training.

Often non compliance reports raised on the training clause of the standard relate to records. However without adequate training in procedures, work instructions etc then the documented quality system will never produce the anticipated benefits.

Training is essential to create the desired attitude change towards quality and it must cover all levels of the company. The implementation of sound training programmes can achieve the desired attitude towards quality awareness and provides a base from which Total Quality Management becomes a reality.

The continued adoption of quality management systems in all sectors of industry as a mechanism of improving product and service quality indicates the usefulness of well documented and implemented systems.

Certification of the system by an independent third party organization such as LRQA is not a requirement of the assessment standard. However, in the current commercial climate, many end users are demanding evidence of such certification and this is driving the market awareness for formal certification.

Systems implemented solely to satisfy end user demands seldom have outstanding success. The desire and belief in quality and quality systems must come from inside the company if really success is to be achieved.

Basically there are no real barriers to the shipping industry in adopting quality management systems - it rests with the commitment of the company and their desire to provide a quality product or service.
Quality assurance in ship operation
The ISO standard, certification, the role of classification societies
J.R. Smit

Quality – Definition

In typical "quality assurance" style I should perhaps start by giving some definitions of the terms used. One of the most difficult terms to define is "quality". The ISO standard 8402 - Quality - Vocabulary defines quality somewhat dryly thus:

The totality of features & characteristics of a service that bear on its ability to satisfy stated or implied needs.

Elsewhere and more simply quality has been defined as the ability of a service to satisfy a given need. Coupled with this definition it has been observed that the concept of quality is not static - constant improvement in quality is considered necessary to retain (never mind improve) market share. In some instance quality is associated with a statutory requirement to establish if a product or service is fit for purpose. In this respect our expectations of quality which were perfectly acceptable 100 years ago are not acceptable now. When Columbus crossed the Atlantic it was sufficient to arrive (almost) alive. Now we expect to make the same journey on schedule with the minimum of discomfort and without damage to cargo.

Quality – Pinnacle of Excellence?

Because of the richness of the English language we are sometimes tempted to think of quality as the pinnacle of excellence but within the scope the subject we are addressing in this seminar such thoughts must be discarded in favour of the definition given in ISO 8402.

The same ISO standard defines quality control as:

The operational techniques & activities that are used to fulfill requirements for quality.
In other words, quality control is the method by which a manufacturer or service supplier measures and monitors the product during manufacture or supply to make sure that intended standards are maintained. For a manufacturer this will include accurate measurements of components to make sure that parts will fit together and meet intended standards of appearance and performance. For the supplier of a bus service quality control might include monitoring the maintenance of a schedule or perhaps regular inspection of hardware for cleanliness and continued serviceability.

Quality assurance is defined in ISO 8402 as:--

All those planned & systematic actions necessary to provide adequate confidence that a service will satisfy given requirements for quality.

From this definition it can be seen that quality assurance has demands and requirements additional to those of quality control. To produce confidence in the system or product it may be necessary to provide additional checks and maintain records for both internal and external use.

Good quality control may be seen as an essential ingredient of quality assurance. Indeed ISO 9004 says:--

A quality management system has two inter-related aspects:--

a) the company's needs and interests
   - For the company, there is a business need to attain & maintain the desired quality at an optimum cost;

b) the customer's needs & expectations
   - for the customer, there is a need for confidence in the ability of the company to deliver the desired quality as well as the consistent maintenance of that quality.

And what about the "quality" (totality of features etc.) the supplier may be aiming to achieve? This may be stipulated in a contract and/or in the professed standards of the supplier. ISO 9002 in fact requires the supplier to define and document its policy and objectives for, and commitment to, quality in a quality policy. A definition of quality policy is furnished by ISO 8402 as:-
Quality policy: The overall quality intentions & direction of an organisation as regards quality, as formally expressed by top management.

Quality management

But I digress. You have not yet been given a definition of quality management nor yet of quality system. Again ISO 8402 gives definitions for both:-

quality management:- that aspect of the overall management function that determines & implements the quality policy.

quality system:- the organisational structure, responsibilities, procedures, processes & resources for implementing quality management.

The Standard

When we talk about ISO 9002 we should really address a series of quality standards which it is convenient to refer to as ISO 9000 although more correctly this is the first number of a current series of six inter-related standards.


ISO 9001:1987 Quality systems- Model for quality assurance in design/development, production, installation and servicing.


As you can see from the date suffix on ISO 9004-2 this standard has only recently been published.
In its opening paragraphs ISO 9000 declares its purposes to be twofold:

- to clarify the principal quality concepts
- to provide guidelines for the selection and use of ISO 9001/2/3 for internal quality management and external quality assurance purposes.

The three models (ISO 9001/2/3) each describe those elements of a quality system considered appropriate by the authors for a specific span of activities. ISO 9001 is considered to be most appropriate in situations where a contract specifically requires design effort and the product (or service) requirements are stated principally in performance terms or they need to be established.

ISO 9002 is considered to be the most appropriate model for contractual situations when the specified requirements are stated in terms of an established design or specification.

The third model is considered most appropriate for situations where the product is complete and only requires inspection and test before delivery.

For some reason it is often stated that ISO 9001 is the highest or most stringent of the three models. It is not. It simply covers more topics since it must cover the requirements of design and post-delivery servicing.

Criticism of the Standard

In terms of ship management ISO 9002 is considered to be the most appropriate of the three models and it is at this point that a degree of criticism invariably appears. The Press of late has been liberally sprinkled with cries of horror that the Standard is meant for manufacturing industries and doesn't meet the needs of the shipping industry. It is correct that the Standard can be difficult to interpret within the requirements of some industries but it is not correct to say that it is not applicable to services. The Standard is written with the needs of both manufacturing and service industries in mind as can be seen from the several references in 9000 and 9004 to "product or service". The key lies within ISO 9004, especially since the publication in September this year of ISO 9004 part 2 which amplifies the needs of the service industries. ISO 9004 is a much-neglected part of the series yet it is essentially the heart of the
series since it outlines the philosophy behind it. All too frequently users refer solely to the chosen model. ISO 9004 deserves much greater attention, especially when applied to service industries.

An important statement in ISO 9004 is:—

An effective quality management system should be designed to satisfy customer needs and expectations while serving to protect the Company's interests. A well-structured quality system is a valuable source in the optimisation and control of quality in relation to risk, cost and benefit considerations.

With regard to scope and field of application ISO 9004 says that the selection of appropriate elements in the Standard and the extent to which they are adopted and applied depends on such factors as the market being served, nature of product, production processes and consumer needs.

The main difficulty in applying the Standard so far as third party certification is concerned is not any lack of suitability for the service industries; it is because the Standard and its various models was designed principally for direct contractual situations. During pre-contractual discussions the first and second parties can agree which of the models are most appropriate and within the model which elements, if any, are unnecessary.

As for the suitability of the Standard for service industries it is significant that more than 25 per cent of the certificates awarded by BVQI have been to service companies and it is believed that a similar proportion have been awarded by the other major accredited certification bodies. Some of the areas of activity in which organisations have so far been certificated include:—

- Education
- Road transport
- Legal services
- Consultancy
- Shipbroking
- Ship agency
- Freight forwarding
- Technical ship management
- Tank cleaning
- Distribution & storage
Certification

When we talk about certification to ISO 9002 we are implying that an organisation's quality system has been tested against this particular quality standard model and, within the agreed requirements of the industry concerned, has been found to comply. This type of certification is somewhat different to the certification of a product (e.g. the issuance of a type approval certificate by a body such as Bureau Veritas or indeed the classification of a ship). Product certification has been with us for years - certainly since the days of Henry VIII with the branding of cannons and since the appending of an assay mark on fine metals. It was perhaps understandable therefore that, with the advent of such a certification procedure to a standard that is somewhat more subjective than those associated with the certification of a product that some attempt would be made to regulate the standards of the issuing organisations. The U.K. and Holland were the first countries to set up formal systems for accrediting certification bodies. Both use the criteria laid down in the European standards EN 45011 and EN 45012 as the basis on which to assess whether or not to accredit a certification body.

The UK accreditation body is the NACCB (National Accreditation Council for Certification Bodies). In Holland it is the RVC.

The NACCB assesses an organisation by examining its quality manual and operating procedures. This includes observing a selection of assessments. Once accredited the certification body is subjected to regular procedural audits by the NACCB.

The certification body is only accredited to issue certificates under the Government Mark for sectors of industry in which it has proven capabilities and expertise. The Department of Trade & Industry publishes a register listing all accredited certification bodies and giving their accredited scope. The certification body may apply for an extension of scope and, given the relative infancy of the system both the list of bodies and their individual accredited scopes are under constant review.

One of the criteria laid down by the NACCB is that all assessments carried out must be led by a registered lead assessor. To gain registration an assessor must have attended
an approved course, passed the course examination and have taken part in a number of quality assessments. In addition the assessor must be professionally qualified, usually to degree level but it is possible to accept alternative qualifications if the candidate has taken part in a greater number of assessments. In this way the national accreditation body sets out to maintain a level of consistency in applying a standard which remains highly subjective.

From the above it can be seen that to date the only certification "watchdogs" are national ones. This is probably the main reason why the major international classification societies have so far worked through comparatively small British registered subsidiaries to issue system certification. As the need for certification becomes more international in nature- as is the case in the marine industry- the case for an international watchdog becomes stronger.

ISO 9002

ISO 9002 is divided into the following paragraphs:-

Management responsibility
The quality system
Contract review
Document control
Purchasing
Purchaser supplied product
Product identification and traceability
Process control
Inspection & testing
Inspection, measuring & test equipment
Inspection & test status
Control of non-conforming product
Corrective action
Handling, storage packing & delivery
Quality records
Internal quality audits
Training
Statistical techniques

While these are the 18 main paragraph headings we could re-group them as:-

THE CONTRACT
THE MANAGEMENT & ORGANISATION
QUALITY CONTROL
RECORDS
The contract

The contract is a good starting point not only for us but also for the assessor. It is the "contract" which determines the "totality of features etc." This determines the stated or implied needs.

The Standard requires the supplier to have procedures for reviewing the contracts it enters into with clients. The object of the review is to ensure that the requirements of the contract are adequately defined and documented, that any requirements differing from the tender are resolved and that the supplier has the capability to meet contractual requirements. Later, where the Standard talks about process control it can be seen that the supplier must identify and plan the service procedures which directly affect the quality of its services. It also obliges the supplier to ensure these processes are carried out under controlled conditions.

From a study of the contractual obligations entered into by the company and with knowledge of the services the company claims to offer the assessor can gain some idea of the range of processes which the company's quality system might need to control. The assessor must then conclude which of these procedures might be expected to be documented.

Suppose for example that the company has signed a BIMCO Shipman agreement and has agreed to provide Technical Management and Crewing services, as defined in the standard BIMCO form.

In such a case the assessor would expect to find written evidence that the company had addressed all parts of the BIMCO form and verified that it had the ability and facility to meet its requirements together with any agreed riders placed on it by the client.

Furthermore the assessor would look for evidence of company procedures and specified requirements for:-
- locating and selecting competent crewing sources
- verifying that these sources were sourcing personnel in accordance with specified requirements
- monitoring performance (of crewing source and of personnel provided)
-arranging prompt and reliable delivery of crew to and from vessel (sourcing suitable travel agents)
-specifying and monitoring training requirements
-specifying shoreside skill and competence levels
-drawing up repair/conversion specs
-vetting and placing drydock and voyage repair subcontractors
-verifying efficacy of repair work
-following class and statutory requirements
-issuing specific and necessary operating procedures and standing orders (e.g. cargo hold cleaning, planned maintenance schedules, fabric inspection rotas
-checking and recording the continued operations of the crew and the condition of the vessel.

The assessment

When a certification body assesses a company to the Standard the process is quite simple. The company makes a written application to the certification body stating the model which it seeks to be certified to and the scope of it's activities. At this stage it is important that the company establishes that the certification body it selects is accredited for the scope of activity concerned. If it is not then the certificate subsequently issued cannot carry the national quality management system mark.

The procedure followed by BVQI is to first review the company's quality manual to see if this covers the requirement of the model. The manual should be submitted for review at least six weeks before an assessment visit is required. If the quality manual does not contain a list of the procedures currently operated by the company then such a list should be drawn up for submission with the manual. If some areas are not clear, or clearly do not comply, the company is advised in writing. It may be necessary to modify the quality manual prior to the assessment proceeding.

The manual assessment is carried out by an assessor nominated to be the team leader who, based on the preliminary examination of the quality manual and the questionnaire completed by the applicant will get together an assessment team and draw up an assessment timetable. Depending on the size of the company and the geographic placement of its vessels the team will usually be not less than two nor more than three assessors.
The assessment starts at the administrative office of the company, with a meeting chaired by the team leader and attended by the company's senior management and the members of the assessment team. The main objectives of this meeting are to confirm the scope of the certification, explain the procedure to be followed during the assessment of the offices and selected ships and to discuss any specific requirements or difficulties with the proposed timetable.

The team then splits up to carry out the assessment as far as possible within the agreed timetable. It may be necessary for the company to provide each member of the assessment team with a guide to take the assessor from one department to another. It is preferable that these guides are familiar with the Standard and with the various company procedures.

The assessors visit the appropriate departments of the company to ensure that, based on a random sample, all relevant areas of the Standard are covered. Some departments can be expected to be tested against more parts of the Standard than others.

If the assessor discovers that relevant parts of the Standard have been omitted or are not being effectively implemented he will immediately advise the appropriate section head or the appointed guide of the nature of the non-conformance. Set times will be appointed during the assessment at which the assessment team will confer. At these sessions, if time permits, the assessors will draw up formal non-conformance reports and hand them to the company's appointed quality representative. Each non-conformance is presented on a separate but brief report. This report states the paragraph of the Standard concerned and states the nature of the non-conformance. The company has the opportunity to sign that it agrees with the non-conformance and space is provided for the appropriate person in the company to propose a corrective action. The report is drawn up as soon as possible since in many instances it is possible to clear the non-conformance before the first part of the assessment is completed.

In any event at the end of the assessment of the company's offices the team leader, in conjunction with members of the team, draws up non-conformance reports for each of the non-conformances witnessed together with an overall summary of all of the reports. A closing meeting is then held together with representatives of the client's senior management at which the team leader advises whether or not
there are outstanding non-conformances and discusses the course of any outstanding corrective actions. At this stage the team leader will select which vessels the team wishes to see. In general a ten per cent sample will be selected but where several distinct types of vessel are concerned (e.g. a mixed fleet of ro-ros and gas ships) the sample must be representative of the whole fleet.

A timetable will be drawn up and suitable dates arranged. Generally from one to two man-days should be allowed for each vessel. Assessment of the vessels will follow a similar form to that at the company's office and any non-conformance reports will be handed over to the company quality representative immediately on completion of each vessel assessment.

When all of the selected vessels have been assessed an overall summary will be forwarded to the senior management of the company. It has been found in practice that in most instances outstanding non-conformances can be cleared by correspondence but occasionally it may be necessary to return to the site of the non-conformance to verify that the corrective action was truly effective.

Maintenance of Certification

Certificates are issued with a validity of three years and are subject to satisfactory six-monthly surveillance visits. These visits are planned such that all relevant parts of the Standard are addressed over the three-year period. The visits will also be planned to include several of the company's vessels over that period. Usually vessels other than those seen in the initial assessment will be selected.

Ship management certification

Although this paper is principally about the application of ISO 9002 to ship management it is opportune to say something about the Bureau Veritas Ship Management Certification Scheme. While this scheme utilises some of the concepts of ISO 9002 it is not intended to comply with the Standard in full. That is why the scheme is offered by Bureau Veritas and not by BVQI.

The main objective of this scheme is to assess a company's management systems to see whether the safety and environmental pollution management requirements of IMO are being met. The scheme was introduced as a response to the
publication of IMO Res 647 (16) with the object of providing companies who so wished with a Certificate of Conformity stating that as far as could be ascertained by an independent assessment the company was meeting the requirements of that Resolution. At the time of presentation of this paper the original Resolution has been revoked and a broader document has been developed. There is now some pressure from some Administrations to make the new requirements mandatory. It must be clearly understood however that while some parts of the Resolution bear a passing similarity to some parts of ISO 9002 the Resolution is not a quality standard; neither is the possession of an ISO 9002 certificate any guarantee that a company is effectively implementing the requirements of the Resolution unless of course the company has built in the requirements of the Resolution into its quality policy statement and the issued certificate has taken it into account. The Bureau Veritas Ship Management Certificate is intended for those companies who do not wish to or are not ready to implement the requirements of ISO 9002 but who want to be satisfied that they comply with the safety and environmental protection requirements. Nevertheless we have utilised those aspects of ISO 9002 which we consider provide a basic operating system against which an assessment can be made.

Benefits

Finally I would like to say something about the benefits of the ISO 9000 series to ship operation.

As a buyer (and it must not be forgotten that owners are major buyers) knowledge of the standard increases your negotiating power when purchasing. It provides you with a tool to compare the probabilities of several suppliers to consistently provide the service or product you require. By buying from certificated companies you can reduce your own inspection requirements.

As a supplier the Standard provides you with a valuable management tool, reducing or eliminating wasteful effort and providing a means of continually assessing your procedures. Moreover, by having your quality management system certified by an independent body you can demonstrate both inside and outside your company that your quality management systems meet an Internationally recognised standard.
Management systems in shipping: 
Quality or Safety Management, do you follow IMO or ISO?
P.C. Mackenbach

ABSTRACT

Quality Assurance, Quality System Certification, Quality Management and Safety Management are terms, more and more commonly used in shipping. Each of them represents different aspects of two trends that shipping companies must face: "Quality" and "Safety". Both lack of Quality and lack of Safety can be considered as a cause of financial losses to a company. They are however of a significant different origin. Quality is entirely market driven where safety is the avoiding of damage to the vessel, the people on board, its cargo and its environment. Although there are common causes why losses occur and hence some overlaps there also exist considerable differences between the management of quality and safety. The purpose of this paper is to illustrate these similarities and differences and to place both Quality and Safety in shipping in perspective.
SUMMARY

Det norske Veritas, the norwegian classification society, has been in the front line of technological Safety at sea for over 125 years. Already in the early eighties however it was recognised that over 80% of all marine accidents do not originate from a technological cause, but result from what is called the "human error".

Based on its world wide experience with Quality assurance in the shore based industry, extending over more than 15 years, DnV is of the opinion that more than 95% of these human errors are caused by lack of knowledge, lack of skill, lack of instruction or lack of motivation of the people involved. In other words human error is to be seen as the symptom of a failure in the management system, and not as the real cause of accidents.

This justifies the conclusion that 80% of all accidents in shipping are caused by failures in the systems through which vessels are managed. Therefore DnV has issued its own tentative rules for the "Management of Safe Ship Operation and Pollution Prevention" in July 1990. This adds an other standard to the numerous standards the industry has been confronted with in the recent past. DnV is however of the opinion that none of the standards, adopted within shipping up to now addresses Safety specifically enough, whilst at the same time leaving the operators sufficiently freedom to find organisational solutions which suit their own organisation.

Whereas the DnV Rules are based on the principle that management shall systematically work to avoid "unsafe conditions", "unsafe acts" and to "maintain emergency preparedness" at all times", the Rules allow other standards to be added at the same time.

Where IMO, port states, insurance companies, charterers and others in the game tend to come up with seemingly conflicting requirements towards the management systems of ship operators this last aspect is of great importance.
On the other hand it is to be expected that within short time IMO will adopt a common safety management system standard for the maritime industry, the Safety Management Code which will be made compulsory for large parts of the world fleet. As a consequence many of the standards, being used today will most likely disappear or be modified to conform the IMO requirements.

Due to the specific nature of shipping DnV has opted not to use its existing organisation, which mainly is engaged in Quality System Certification for the manufacturing industry.

DnV uses people with experience in shipping which have been specially trained to understand and appreciate the specific problems which the shipping industry has in the management of safe ship operations.

DnV is able to certify that a Safety management system complies to its own tentative rules. These Rules cover the existing IMO guidelines completely. In addition a certificate can be issued that the management system meets the requirements of the ISO standard, if required by one of its accredited organisations.

Since Safety and Quality management systems are new to many companies, DnV also can assist in providing its experience in the development of the system. This however is done at arms length in order not to compromise DnV's integrity.

MANAGEMENT SYSTEMS

Ships get damaged, cargoes contaminated, people hurt or killed, clients are lost, beaches are polluted. This not only represents a significant cost to the shipping industry, either direct or by ever increasing insurance premiums, but it is giving shipping a bad reputation with the broad public. Politicians react on this and the result is a continuous tighter system of requirements and regulations from authorities and port states and more intensified inspections which the industry has to live with.

The progress made in technology has given an ever increasing improvement of maritime safety and service quality. However in spite of this improved technology, accidents continue to occur with what seems to be increasing financial losses to the individual owner or his insurance companies.
It has been recognised already some decades that over 80% of what goes wrong in every sector of industry is not the result of failing technology but the ultimate result of failing human behaviour. Further investigation has learned that only less than 5% of this human failure can be classified as the so called human error, the error which happens whilst the person knows and is motivated to behave correctly.

Considering that instructing people how to act and to motivate people to comply to their instructions is a management task, this justifies the conclusion that around 80% of all accidents are the result of failing management.

This view has resulted in an increasing tendency with authorities, insurance companies, charterers and other interested parties to obtain more confidence that management has adequate control over the behaviour of the people they manage.

Since this behaviour is primarily depending on the companies policy towards quality and safety and the procedures and working instructions which detail these policies down to work floor level, the requirement that these policies, procedures and working instructions are properly documented is rapidly increasing.

HUMAN BEHAVIOUR
SAFE ACTS / CONDITIONS

The principles behind management systems

These policies, procedures and working instructions shall be assembled in a systematic way in what is called a Safety- or Quality management system.

The most known requirements which ship managers are confronted with are IMO Resolution A647(16) (Safety Management) and ISO 9000 (Quality Assurance and Quality Management)
QUALITY ASSURANCE AND QUALITY MANAGEMENT

Quality is realised when a client has the perception that a supplier's delivery meets his expectations.

This implies that the three aspects which need to keep control of in managing quality are:

- The perception the client has of the supplier's products/services
- The expectation the client has to the supplier's products/services
- The noticeable characteristics of the supplied products/services

During the past decades, shore-based industries have massively adopted a strategic view on the quality of their products/services since they realised that customer satisfaction was a pre-condition for their commercial survival.

In addition, analyses have shown that as much as 30% to 40% of their turnover was lost due to non-quality, resulting in rework, scrapping of products, after sales services, lost management and commercial efforts, etc.

This made them realise that substantial savings could be achieved by replacing the traditional final inspections by in-process inspections in order to verify that the products/services still comply with the specified requirements. If needed, corrections can thus be made before unnecessary value is added.

Because they were aware that non-quality is the result of human behaviour, they realised that they had to include their policies and procedures which should achieve their strategic and cost-saving objectives in management systems. Since the requirement to have an implemented Quality System also became an element in the commercial interaction between companies, the industry has achieved almost worldwide consensus through the International Standardization Organization on one common standard to which these Quality Systems should comply, i.e., the ISO 9000 standards.

These standards are commonly used by both manufacturing and the service industry and are now so widely accepted that shippers of goods start to require from the maritime sector to comply with this standard as well. This because shipping is one of the many services they buy, and they want to have the confidence that the shipment of the goods, either bought or sold, does not lead to deterioration in quality.

The result is that more and more ship operators are getting faced with the requirement that they have to comply with the ISO 9002 standard. This standard, however, does not refer to safety or pollution prevention at all and every attempt to restructure the ISO standard to include safety as an additional issue has, in our opinion, created a standard which may be implemented in the management company ashore, but is impossible to implement onboard ships.

This is, because the shore-based organisation of a ship operator has some similarity with other shore-based industries. The operation of the vessel, however, and the unique role the master has, is entirely different to any other industrial process.
This criticism even is applicable to the ISMA Code, a very worthwhile initiative of a group of ship management companies (known as "the group of five") which resulted in a derivate of the ISO standard. In defence to alleged criticism to the quality of their services the International Ship Managers Association has made compliance to the requirements of the ISMA Code a condition to their membership.

SAFETY MANAGEMENT

Safety in the shipping industry is realised when any damage to the vessel, its crew, its cargo or its environment is avoided.

Society at large, especially in the western countries, is getting more and more demanding towards the quality of life and gets more aware of the limitations which industry puts on them in this respect. Telecommunication technology has been confronting them with the most dramatic consequences of disasters as with the Herald of Free Enterprise, Scandinavian Star, Exxon Valdez, what happened off Genoa last year and many others.

This has triggered public criticism towards the way safety of ships operations is managed.

Result of a recent analyses of 918 P & I Claims > £ 100,000 by the U.K. Club

CAUSES OF MAJOR CLAIMS

In turn this resulted in a political reaction which not only led to debates about double hull/double bottom concepts for tankers or other technological safety barriers, but also the role of the human element in all these maritime disasters has been extensively emphasised. Inevitably this has resulted in politicians and authorities criticizing the quality of the management of ships operations.

In response to this a resolution was adopted within IMO, known as res. A647(16) and which may seem to be only a "Guideline for the Management for Safe ship Operation and Pollution Prevention" but should be seen as a very strong signal on how the thinking within regulatory bodies will develop in the future. The guidelines under IMO A647(16) call upon the shipping community to develop and implement management systems in their companies to take proper control of safety and pollution prevention.
A number of port states have interpreted this signal and since short a Safety Management System is mandatory for all vessels carrying passengers in Norwegian waters. Other North-European port states are working on incentive schemes in which safe vessels get benefits in reduction of harbour duties, priority in pilotage etc. In these schemes an implemented Safety Management System scores high credits.

A different approach has been taken by the U.S., who in response to the Exxon Valdez accident, through the Oil Pollution Act 1990 have put repressive and unlimited financial consequences in front of the ultimate owner of any vessel that can be held liable for the pollution of American water.

In addition to this extensive policing has been implemented on vessels entering U.S. waters. Realising that this reactive approach is to labour intensive and not fully effective, they started to work on "greatly simplified inspection processes", based on the USCG "model company concept", which requires a Safety Management System to be implemented as well.

For the insurance sector Oil Pollution Act 1990 ads new uncertainties in times that substantial losses are suffered in the maritime sector as well. Consequently insurance companies start to look more critically at ship management. Since short signals are vented that premiums should be more in line with the actual risk for the insurance companies and that this risk should be based on a more forward thinking risk assessment instead of retrospective statistics.

Now already a some insurance companies use pre-assessment of the ship operators Management System as a main tool in assessing their risk (and possibly rejecting it). When this policy proves to be economically successful this trend will be taken over by others.

In addition a number of operators started to realise that not only increased insurance premiums will put pressure on their competitiveness. They also realise that most of the small damages below their franchise limits, which up to now they have accepted as being inherent to the business they are in, can be reduced by limited investments and consequently can increase their profitability dramatically.

**THE DnV TENTATIVE RULES**

Based on its extensive expertise with Safety and Quality Management Systems together with its independent position DnV launched its own Rules for the "Management of Safe Ship Operation and Pollution Prevention" in July 1990 to serve the maritime industry, which contains so many different interests.

These Rules encompass the IMO Guidelines entirely and specify in global terms how the requirements in these guidelines can be met.

They require that to obtain a certificate the company shall have policies towards the safe operation of its vessels and these policies shall be detailed in procedures and instructions.

There shall be a management system which clearly defines responsibilities, reporting lines and working methods and which shall not only cover the ship board organisation but the shore based organisation as well. This because within today's ship management the
influence of shore based management on the ships operations is so big that safety on board is bound to be affected from ashore.

Different Management Standards in Shipping and how they overlap

However the unique position of the master being ultimately responsible for the safety of the vessel is maintained. In addition he is assumed to be the manager, being responsible for the management system on board within the companies policies.

Contrary to many other standards which are emerging in the shipping industry the DNV rules are not intended to be a straight jacket but are formulated in a global manner in order to allow companies to find their own organizational solutions.

Based on the philosophy that every trade has its own characteristics and that no two companies are the same the Rules allow operators to base their management system on their existing organisation and working procedures. It is required that the operator shall analyze the risk in his operations in a systematic manner and create the necessary organisational safeguards against the accidents which are most likely to happen.

This selection of "the vital few and the trivial many" is considered to be one of the most essential aspects in the development of management systems.

The amount of paper shall be kept to the absolute minimum! It shall be avoided that procedures are developed for activities which are trivial to safety. This has a negative effect on the acceptance of procedures and adversely influences the safety behaviour of people. Besides care shall be taken that procedures or instructions shall not replace the existing skills of people. Either such procedures are not accepted or, what is even worse, they contribute to the reduction of skills after some time. The use of check lists for routine operations is recommended in stead.

In selecting "the vital few" activities which are crucial to safety managers shall assess all activities in their operations to the key requirements in the DnV Rules, i.e.:

- Safe Practices
- Safe Conditions
- Emergency Preparedness

both ashore and on board, are maintained at all times.
The DnV Rules is the only standard which requires explicitly that the management of ship operations shall:

* Comply to mandatory Rules and Regulations.
* Observe industries own perception of safe practices, as laid down in industry guides and standards.
* Management apply their minds to safety to identify possible additional hazards not covered by regulations or standards.

The DnV Rules are formulated in a way which allows flexible interpretation. They are based on general loss-control principles, assuming Accidents and Pollution to be the main losses to be controlled. Because some of the administrative elements from the ISO standard have been adopted this easily makes it possible to define Quality as a potential loss in addition. This gives full opening to include requirements from other standards to the management system, which allows for certification to different standards at the same time.

**DnV's EXPERIENCE WITH SAFETY MANAGEMENT CERTIFICATION**

The DnV Tentative rules for Management of Safe Ship Operation and Pollution Prevention were issued in July 1990. So far, 6 companies have passed certification. More than 30 companies have signed contracts for future certification when system development and implementation is completed.

To keep in contact with an experienced auditor during system development, and get feedback as system elements are worked out, is a definite advantage to the companies.

Development based on project plans, and being committed to specific milestones, assists in keeping up the pace and in providing commitment from management and participants. Working against a fixed date for the implementation audit is particularly important in this respect.

Even if the audit shows that many system improvements have to be performed, the companies do not consider this as a negative experience. On the contrary the findings of an external auditor tend to support motivation for system development and implementation.

Contrary to what some people believe most auditees consider the audit to be a pleasant exercise. One explanation may be that most people find pleasure in discussing their work with others-and that is what an audit is, planned and structured job discussions.

The audits have confirmed that perhaps the most important qualification an auditor should have is the communication skills, particularly the ability to listen to and understand people. However, one of the conditions for that is a thorough professional understanding of the area subject to audit.

Establishing the audit capacity that the possible enforcement of mandatory requirements of safety management will require is a major undertaking that should not be underestimated. Audits should support motivation and promote safety awareness—even if they reveal much that must be improved.
FUTURE DEVELOPMENTS

Maritime industry for the time being shows a hesitant attitude towards accepting Management Systems as a valuable tool to their operations. This has been seen in shore based industry before and it is to be expected that more and more operators will recognise that a management system is not a limitation to the so much appreciated freedom of the ship manager, but an asset which generates revenues.

The driving forces behind "Quality System Certification" are commercial, strong and self-sustaining—and for the moment quality system certification gets most of the attention.

In a longer time perspective, however, the impact of Safety Management development may very well be the most important one.

At its meeting in May 1991, the IMO Maritime Safety Committee (MSC) decided to develop mandatory requirements to Safety Management. The IMO Guidelines were not suited for certification of Safety Management. Consequently, MSC also decided to work out the "International Safety Management Code".

To avoid too many different Management Standards being imposed on the industry, development within IMO of the "International Safety Management Code" should be supported. This is the organisation most likely to succeed in providing harmonisation throughout the industry.

In making this code mandatory throughout the industry some crucial questions still have to be answered.

* How long time will the shipping industry need for its views on Safety Management to mature?
* How long time will be needed to establish the enforcement capacity that mandatory requirements will demand?
* How long will the shipping industry need to respond to mandatory requirements to safety management?

Other just as important questions are:

* Can safety management be implemented through mandatory requirements at all?
* Have more positive means to ensure the support from the industry that is required?
* Should the Maritime Administrations and others choose a strategy of "carrots" to those who succeed in maintaining high standards and "sticks" for those who do not?
* If the industry organizations support the development towards mandatory safety management requirements will this than stop the increasing development of detailed technical and operational requirements.

The answers to these questions should be based on maturity and experience and not on prejudices and misconceptions. Safety Management development represents a new area in shipping. Success is vital. If the industry needs time, then time should be given.
Abstract
Since the 1950’s a large number of vessels have been operated in ocean crossing voyages with the help of shore based ship weather routing.
Recent developments in fast PC’s and data communication via satellite have made it viable to transmit on request relevant metocean data to the ship where the optimal routing procedure is executed on the onboard PC using the predicted metocean data, available climatological data and the ship performance models.
The optimal route together with the predicted vessel performance parameters along the optimal route such as speed, rolling, pitching, fuel consumption and probability of slamming and shipping green water are presented to the operator in an ergonomical justified way. Interfaced with a performance logging and analysis module the system is called a voyage management system.
Descriptions are given of the used isochrone method for minimum time routing, the ship performance models, the data logging system and the system integration.
Simulation results and field test plans on board of an ocean going tanker for spring ’92 are presented.

1. Introduction.

Strategic ship weather routing is a procedure to determine an optimal route for a particular vessel on an ocean transit, based on the forecast of weather, sea state and ocean currents.
Optimization can be performed in terms of
(i) minimum passage time.
(ii) minimum fuel consumption within specified passage time.
(iii) minimum damage to ship and/or (deck) cargo by the sea.
(iv) maximum comfort to passengers.
(v) a combination of the above mentioned criteria.
For most commercial purposes a combination of (i) and (iii) will be applied in the startphase of the voyage, going gradually to the combination of (ii) and (iii) in order to arrive just in time at the destination.
Strategic routing will not avoid high (head) seas under all circumstances; in adverse conditions the shipmaster has to heave to and decide...
on course and speed to save ship and cargo for heavy damage. The decision process for these short time goals is called "tactical routing".

The shipmaster is responsible for the routing decisions, he will do this on the basis of his appreciation of the ship performance, the forecasts of weather, sea, currents and icelimits, conditions in the Charter and possible instructions from the shipowner. As it is not feasible for the shipmaster to make a quantitative analyses of different routes, he will often make use of a routing advice from a Weather routing bureau.

An inquiry under 100 active shipmasters showed that 80% of them had positive experiences with weather routing advices, although most of them had additional requirements for the advice given [Teeuwen 1988]. A similar investigation under Japanese shipmasters showed that 65% of them made regularly use of routing advice form a weather bureau. Their confidence had grown in recent years, but they also expressed additional wishes for the quality of the information given [Yamamoto 1987].

The most important shortcomings of present weather routing advice are:
- only one so called optimal route is advised, no alternatives are given;
- backgrounds and motivations of the advised route are insufficient; the shipmaster is not able to validate the advice given;
- only minimum time routes are given;
- the exchange of information between routing bureau and ship should be improved.

In spite of these shortcomings remarkable successes are achieved with weather routing. During 25 years of service the Royal Netherlands Meteorological Office achieved about 80% successfull routings, i.e. the advised route was shorter in time than the greatcircle route. The average time saving from the English Channel to the Gulf of Mexico was 12 hours and to New York 4 hours; the fuel savings were estimated 3-5% [KNMI, 1985]. Because routed vessels encounter less high (head)seas - Constantine (1981) mentions twice as many unrouted ships in significant wave heights of more than 6.5 m than routed ships - the damage on routed ships will be reduced. According to the Naval Weather Service in the USA (1976) an average ship will experience on the average 1000 USD damage per day in significant wave heights of 6 m., whereas this increases dramatically to 10.000 USD per day for waves of 8 m. height. The system described in this paper will cope with the shortcomings of today's weather routing, all the available and necessary information for routing decisions is then where it should be: on the ship's bridge. The system will assist shipmaster and bridgeteam in performing a safe and efficient voyage and with the prediction of a reliable time of arrival.

2. The modified isochrone method.

The t-hour isochrone is defined as the outer boundary of the attainable region after t hours of passage time taken into account ship performance and environmental factors. A practical way to compute the t-hour isochrone is described in Spaans and Hagiwara (1987). Every next isochrone (after 12 hours) is found by a search procedure where
the maximum distant point is determined in a small subsector originating in the point of departure. Every point on an isochrone determines a track backwards to the point of departure. When the computed isochrone approaches the destination, the passage times from all isochrone points to the destination are determined; the track segment with smallest sailing time indicates the minimum time route, see figure 1 (after Hagiwara et al, 1991).

The method can also be used to compute the optimal route with the required constant number of propeller revolutions along the route to arrive just in time at the destination, see Hagiwara (1989). Also in Hagiwara (1989) the method is used in a stochastic optimization procedure to predict additionally the standard deviation of arrival time and fuel consumption. The shipmaster is then, for instance, able to decide for a southern route with larger expected passage time but with smaller standard deviation, because of "just in time" requirements.

The method is not suitable for optimization by variation of both course and speed, therefore the isopone method is developed at the Royal Shell Laboratories in Amsterdam. The backgrounds of this method will be published at a later stage.

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**Fig. 1: True minimum time route to Tokyo (thick line)**


An important factor in ship weather routing is the accurate prediction of the ship speed. The fact that a powerful computer is available on-board allows a scientific and accurate calculation method. The calculation of the ship speed is based on Newton’s principle: Force = Mass * Acceleration; this means that the derived ship speed is found when the resulting force on the ship is zero. For the practical application of ship speed calculations this concept was introduced by Journée et al [Journée et al, 1987]. The propulsion force of the propeller must be equal to the sum of still water resistance, wind resistance and wave resistances. With this equilibrium the speed through the water can be calculated. The speed over the ground is found when a current component is added to the speed through the water.

This speed calculation can be made accurately because detailed ship information is used, such as the hullform, engine and propeller characteristics, fouling parameters and the loading conditions. In the final system some of the used ship parameters will be tuned with measurements on board.

An advantage of this speed calculation method is that not only the speed is predicted, but also the fuel consumption and the ship motions are calculated. The operator can set thresholds to ship motions in the route selection procedure for the objected transit. Examples of motion criteria are the maximum number of slams per hour, the average roll amplitude and the predicted time of shipping green water.

4. Weather and communication.

Ship weather routing requires forecast information on wind and waves. Also the current has direct influence on the ship progress. With the newly proposed routing method meteorological and oceanographical information is gathered up to five days ahead by a weather bureau for five ocean regions, covering all major shipping routes. Ships in a specific region can download the prepared dataset for their region by Inmarsat-A satellite communication facilities. The information can be downloaded or updated at any time from a shore based electronic mailbox, on request of the master.

The environmental data are: windspeed (10 meter level) and direction, sealeft, period and direction and swellheight, period and direction. For swell the most dominant group (direction) is taken. The addition of wave period information is a major improvement for routing calculations, since ship motions and therefore also wave resistances are sensitive for wave frequency variations.

Additional to wind and wave information also airpressure at sealevel, icelimits and hurricane information is added. This information will be processed and stored in the datafile for that region. Furthermore an experienced meteorologist will make a general interpretation of the weather, the weather systems and the predicted developments in that region. Also possible errors in the model data are examined. The meteorologist will then write down his evaluation in a bulletin, which is also stored in the datafile.
The written analysis will help the master with his interpretation of the weather, especially in difficult situations. The analysis together with the master's basic knowledge of weather systems and his practical experience with the analysis of weather facsimile charts provides a good basis for a correct interpretation of the weather in his region. Extra meteorological information which is available at the office, but which is not transmitted to the ship (because of high communication costs) will in relevant cases be mentioned in the written bulletin. The extra information can consist of satellite images, other computer model results or special bulletins.

Because transoceanic voyages often take longer than five days, a climatological database is stored onboard with average wind and wave information that can be used after five days. This information is gathered from measurements over a long period of time and is given in monthly averages.

The main advantage of the new approach is that the bridgeteam has a complete overview of the weather up to five days ahead from one reliable source, instead of fragmented information from many different sources.

5. Data logging.

Integrated in the Voyage Management System are provisions to collect and record performance and voyage parameters. A measurement interface is assumed to be available (e.g. the Ship Performance Monitor (SPM) on Shell vessels). The SPM interfaces the shipboard instrumentation (speed log, power meter, fuel meter) and provides the information via a serial line to the Voyage Management System. Real time records are produced and stored on disk. These records provide the possibility to monitor the accuracy of the predictions of the ship model by comparing the predicted parameters with the stored data. The ship model that simulates the behaviour of the vessel is at the basis of the routing calculations and accuracy is therefore required. Provisions to modify the ship model as fouling occurs (hull, propeller) have been made.

The voyage parameters are stored in a voyage log. At regular intervals the progress of the vessel is recorded. The information is stored for future reference but also to facilitate the assessment of the impact of the Voyage Management System at some later stage.

6. The Voyage Management System.

Recently a cooperative development between Shell Research and Meteo Consult Wageningen has been initiated. This cooperation will combine the complementary work and ideas on voyage management and weather routing of both parties. The result of this cooperation will be a voyage management system to be field tested on board a Shell tanker during 1992.
The system is operated on a Personal Computer (PC) and will serve as a management support tool to be used on board. Its functionality includes interactive voyage planning, weather routing, ship performance prediction, performance logging and analysis. The user may select from various optimisation criteria i.e. minimum time, minimum fuel, maximum profitability. A satellite link with a shore based weather data based is provided. The infrastructure to feed this data base with worldwide up to date weather predictions is currently being set up by Meteo Consult.

6.1 System elements.

The Voyage Management System will be implemented in a 386/486 compatible computer. All hardware will be embodied within one PC configuration. A standard Ship Performance Monitor (SPM) and/or other external equipment (e.g. navigational instruments) may be interfaced directly to the PC via standardised interfaces. The voyage management system will have the following functional modules, see figure 3.

a. Integrated navigation.
b. Ship Performance Prediction.
c. Performance Monitoring and Analysis.
d. Weather routing.
e. Voyage Monitoring and Analysis.
f. Communication.

a. Integrated navigation.
GPS will be integrated with other sensors to calculate and maintain a 'best estimate' of the actual position and the speed/course vector. Speed is obtained as speed over the ground.

b. Ship Performance Prediction.
The system will contain a module to predict ship performance in terms of power, speed and related parameters as influenced by loading condition and prevailing environmental conditions. An essential part of the ship performance prediction module is a detailed ship model which has to be tailored to the actual ship parameters. The performance prediction module is called upon by the higher level routing module.

c. Performance Monitoring.
The Performance Monitoring module is optional. Interfacing with a Ship Performance Monitor (SPM) is required. This module will continuously monitor and convert the data from the shipboard instrumentation via the SPM. Performance data will be stored on disk. These logs are accessible for (graphical) inspection.

d. Routing.
The routing module will calculate the course and speed settings leading to the optimal completion of the present voyage. The user is required to select the criterion to be applied (time, fuel, profitability) and define the boundary conditions (motion criteria, arrival
time). As the voyage progresses and the routing calculation is repeated - say - every 24 hours, the results of the voyage so far will be taken into account as well. This implies that any deviations from the original plan will be taken into account.

The weather routing process requires the availability of the following categories of data:

- Voyage data : interactively entered by the user.
- Weather data : communicated to the ship.
- Climatic data : available on disk.

The routing module provides the input to the higher level business model. A maximum profitability routing is constructed from a range of minimum energy routings.

e. Voyage Monitoring and Analysis.

The performance of the vessel in terms of economics and fuel will be logged continuously. A voyage log is constructed and updated as the voyage progresses. The performance will be made visible in relation with the original and the updated voyage plan. The logs will remain available on disk for purposes of inspection at a later stage. They will be the basis of the assessment of any improvement in performance due to the use of the voyage management system.

f. Communication.

Two categories of communication (ship - shore) can be identified:

(i) - Uploading of logfiles (voyage and performance).
(ii) - Downloading of software/datafiles.

(ii) - Collection of weather data.

Meteo Consult is now testing the MEMOCOM 400 system (PTT Telecom). This electronic mailbox system will be used to hold the recent weather data. Users may log in and download the required data sets to the vessel.

6.2 User aspects.

The voyage management system is in fact an information management system. Embedded within the system are the tools to plan and monitor the voyage of a vessel in terms of fuel economics, earning rate and scheduling. An important factor to influence the beneficial effect of this system however is the supply and the quality of weather data. One can assume that the better the quality of the weather data, the more benefit will be gained from operating the system.

The user of a voyage management system (a shipowner) will expect a return on investment and is well advised to provide the means to monitor and measure the performance of such a system. All relevant information for such an analysis is available in the voyage logs as they are produced by the system. Considering the flexibility of the system it is anticipated that any user on board may appreciate the support of the system for specific elements of the operation (planning the voyage, calculating estimated time of arrival (ETA), position fixes). However to obtain an objective measure of the return of the system a central facility for voyage analysis should be part of the organisation of the
shipowner. This will also provide the possibility to advise vessels on the settings of their various fouling coefficients that are included in the performance prediction module.

7. Field test results.

The performance prediction module and the data logging routines were included in a prototype system which has been tested during a field trial on board a tanker in 1989. Both loaded and ballast conditions were tested. The vessel was extensively equipped with instrumentation (wind meter, EM-log, Doppler-log, 2 independent power meters). The standard deviation of the power prediction was 3% over a range of environmental and operating conditions. The system also provided an online measurement ship speed with an accuracy of 1%. The speed estimates were verified with "a Dutchman's log" (oranges). Integrated in the data logging routines are filter routines which correct for bias in the speed log. Examples of the speed log are included, see figure 2. The filter routines also provide accurate estimates of the wake, an important parameter in the performance prediction module.

The performance prediction module and the filter routines will be included in the Voyage Management System to be tested this year.

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Fig. 2: Plot of Doppler, EM-log and EKF speeds versus 'orange' speed 2nd May
Fig. 3: Voyage Management System
Abstract. An on-board voyage optimization system - the Expert Voyage Pilot - has been developed and its main functionalities are described in the paper.

The EVP optimizes the voyage plan with respect to fuel consumption and/or overall costs, considering relevant data as satellite-transmitted wave and weather forecasts, ocean currents, propulsive and kinematic performance of the vessel, seakeeping criteria, charter requirements and restricted areas extracted from electronic sea charts.

The user interface, the interface to electronic chart display (ECDIS), the propulsion model, the motion performance model and the optimization strategy are described, and results from sea trails are presented and discussed.

Introduction Optimizing a ship's route with respect to wind and waves has been one of the navigator's most important duties since the beginning of the sailing era. Whereas it was evident to the ancient navigator, that to reach a place directly against the wind, without special attention to the prevailing winds and sea currents, would be impossible. The challenge in optimization of to-day's sailing lies in the economical aspects involved in sailing the ship.

The past decades have, however, seen a growing interest in weather routing as a tactical tool for increasing both the safety of the ship as well as the economy of the ship. Hence, the development of both automated weather routing system Marks et al. (1968), Witt (1989), Andersen (1988) and Calvert et al. (1991) and design of integrated system for navigation and steering Kristiansen et al. (1989). Of course with the increasing power of small computers the area of development has turned in the direction of development of an integrated voyage planning and optimization system, cf. Loukakis et al. (1991). The development of the Expert Voyage Pilot (EVP) is a step further in the development of such a system containing a total integrated solution to the combined voyage planning and optimization system for on-board use. The EVP has been developed under a EEC-programme, KBSSHIP, with participation from Danish Maritime Institute (DMI), Søren T. Lyngsø A/S (STL), National Technical University of Athens (NTUA) and Krupp Atlas Elektronik GmbH, Bremen.
The User Interface  Routes can be entered and optimized through a graphical interactive user interface. The user interface contains specific interfaces for entering charter contract information, loading information, generation of sea-charts, and managing weather reports. This section presents the sequence of interfaces used to enter and optimize a route.

Appearance of the EVP's User Interface. To present the appearance of the EVP's user interface, this section demonstrates the planning of a voyage and presents different interfaces. First, charter information must be entered. Charter information consists of a sequence of harbours that the ship must visit on her voyage together with arrival and departure times. Harbours are selected from a sorted menu, and their positions are automatically displayed. Duration and distance of the voyage are updated, as harbours are included in the voyage. The charter contract interface is shown in Figure 1.

Secondly, the route must be entered, using the route planning display. Routes are entered, by connecting a set of predefined statically waypoints, using the mouse. When a route is entered it can be optimized by choosing the optimize command on the top pane of the display. Figure 2.3 shows the route-planning display with a non-optimized and an optimized route.

The optimization algorithm described in a later Section calculates a cost optimal or fuel route and determines the speed and heading along the route. Information on both a non-optimized and an optimized route can be retrieved. This information is shown in a window that pops-up on the route-planning display. More information is available for an optimized route than for a non-optimized route.
The information consists of fuel cost, speed, heading, etc. Information for an optimized route is shown in Figure 3.

Information is available both for each segment in a route and for a complete route. It is possible to enter more than one route, optimize them, and compare their cost.

Beside the charter contract and route planning interfaces the EVP also contains interfaces for entering loading information, construction of sea-charts, and managing weather reports.

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<th>Longitude</th>
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<th>Type</th>
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<tr>
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<td>28° 15' 39&quot;W</td>
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<td>Non Fixed</td>
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<table>
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<tr>
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<th>Roll Angle</th>
<th>Vertical Acc. FP</th>
<th>Vertical Acc. Bridge</th>
<th>Lateral Acc. Bridge</th>
<th>Slamming Rate</th>
<th>Deckwear Rate</th>
<th>Shaft Horsepower</th>
<th>Shaft Horsepower Limit</th>
<th>Propeller RPM</th>
<th>Speed through Water</th>
<th>Speed made Good</th>
<th>Heading</th>
<th>Course made Good</th>
<th>Wave Height</th>
<th>Peak Period</th>
<th>Wave Direction</th>
<th>Wind Speed</th>
<th>Wind Direction</th>
<th>Sea-current Speed</th>
<th>Sea-current Direction</th>
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<tbody>
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<td>0.24</td>
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<td>0.00</td>
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<td>57.89</td>
</tr>
</tbody>
</table>

Figure 3. Information on Intermediate Conditions On Route.

Integration to Electronic Chart Display (ECDIS). The EVP communicates with the ECDIS in both the planning phase and the optimization process. To show this the planning scenario is described in the following 6 steps:

1. Step: The EVP generates a file with the definition of the desired background chart for the planning part. This definition will include the positions of the chart corners and the required resolution.

2. Step: The ECDIS then extract only the land areas of the desired chart and generates this as a list of polygons with the required resolution.

3. Step: The EVP User defines now a rough waypoint list of a navigation corridor. (E.g. an island has to be passed on a given side, so only this chart data must be transferred).
This list of desired waypoint positions (latitude and longitude) will be transferred to ECDIS including a value for the width of the "navigation corridor" and a value for the ship's safety depth (e.g. 10 metres).

4. Step: The ECDIS will then select the sea-chart data along the navigation corridor. It extracts and reformats all "forbidden" and "proposed" polygons (incl. necessary attributes) of the selected cells that are defined to be relevant in the list of the object classes. These polygon data will be transferred to the EVP for the calculation and generation of the optimized route.

5. Step: The EVP does the voyage optimization by avoiding the forbidden polygons and integration of the proposed polygons and the attached attributes. The optimized route is then transferred to the ECDIS.

6. Step: The optimized route will be displayed on the ECDIS sea-chart display.

Manual checking and editing of the route may be done on the ECDIS display, to be able to handle small modifications (additional waypoints, etc.). The final route plan may now be transformed to a steering sequence and transmitted to the navigation command system. To decide whether an object has to be transferred to the EVP, attributes are attached to the object. Relevant attributes are:

- Land Area.
- Depth Range: Depth, Dredge, Intertidal area.
- Dumping Ground.
- Restricted Areas such as: Undefined, Offshore Safety Zone, Nature Reserve, Military Area, Restricted Area, Inshore Traffic Zone, Safety Zone, Mine Field.
- Forbidden areas such as: Anchorage Area, Cargo Transhipment Area, Ice Area, Military Practice Area, Offshore Production Area, Traffic Separation Zone.

The non-navigable polygons covering forbidden areas as prohibited or restricted areas will be generated with their available resolution in the ECDIS. From the type of attribute it is evident that not all areas will be relevant as restricted areas to all ships. For instance "intertidal" zones and ice areas will vary with the loading and time of year. Therefore, generation of chart information has to take place at each run of the EVP.

**Satellite Transmission and Handling of Weather Forecasts.**
Forecasts of winds and waves are transmitted by satellite INMARSAT-C, cf. Ref. Guinard (1991) from a weather forecasting center, i.e. the Danish Meteorological Institute.
The INMARSAT-C is restricted for communication of written messages in a 5-bit telex format. This calls for vigilance to the amount of data to be transmitted. The benefit of using INMARSAT-C is that it is simple, relatively cheap and reliable both with respect to the actual transmission and the hardware necessary.

An update of the weather forecast for the relevant ocean area may be broadcast to the system when available and when it has been specified which part of the ocean should be covered. This means that from the ship’s actual position it is calculated where the ship is likely to be at what time within the duration of the next forecast. A short telex message describing the ship’s position and corresponding time in the vicinity of the start of the forecast is given along with a maximum as well as minimum of speed to be maintained, a position of arrival and corresponding time of arrival, and a maximum deviation from the great circle course is sent to the forecasting office. From these information it is decided which points and hours should be included in the forecast and send to the ship. See Figure 4. Only data within the geographical positions and corresponding to a time interval limited by "fast" and "slow" sailing will be included. It is up to the user / navigator to decide which are the appropriate limits on deviations in geographical positions and speeds to be used.

![Figure 4. Selection of Relevant Data for Transmission to the Ship.](image)

A forecast send to the ship once every 24 hours would consist of three files containing the following information: 1) Wind information 0 - 36 hours from 0Z at time intervals 12 hours. The geographical resolution is 1.5 degrees. 2) A short-term wave information 0 - 96 hours at intervals 24 hours and a
geographical resolution of 2.5 degrees. 3) Finally, a combined long-term wind and wave prognosis covering the time 48 to 156 hours at 12 hours intervals and a geographical resolution of 3 degrees.

Each file containing wind or wave information are ranked hierarchically to avoid ambiguity in data available for a given place and time. The EVP will then search for relevant data in the highest ranking data file that contains the relevant data.

Thus, by ranking a 0 - 96 hours wave prognosis higher than the wave / wind 48 - 156 hours, prognosis will make the EVP pick-up information from the first data file (0 - 96 hours) even if it is overlapped in time and geographical positions by the latter data file.

**Ship Model.** A mathematical model describing the performance of the ship was derived from existing mathematical formulations. In this context performance should be interpreted as both the speed and power relation as well as the seakeeping ability of the ship in a seaway. That is the mathematical ship model will for given input of speed and sea and wind conditions calculate the fuel consumption, shaft horsepower, the significant motions of the ship and the probability of slamming or shipping of green water on deck.

**Resistance.** The still-water resistance is calculated using the standard ITTC-formulation:

\[
R_{st,1} = \frac{1}{2} \rho V_s^2 \cdot \left( C_f (1+k) + \Delta C_f + C_A + C_r \right) \cdot S
\]

where:
- \( \rho \) : Density of sea water.
- \( V_s \) : Ship’s speed.
- \( C_f \) : Frictional resistance coefficient.
- \( \Delta C_f \) : Added frictional resistance due to fouling.
- \( C_A \) : Allowance coefficient.
- \( C_r \) : Residual or wave-making resistance coefficient.
- \( k \) : Hull form factor.
- \( S \) : Wetted surface of the ship.

\( C_r \) is a function of both speed, draught and trim of the ship, whereas \( k \) and \( S \) are only functions of the draught and trim, and finally \( C_f \) only a function of speed. A set of \( C_r \) curves representative for a bulk carrier is shown in Figure 5.

Very often information about \( C_r \) and \( k \) vs. trim is not available for the ship, in which case it will be necessary to omit the variation with trim.
To the still-water resistance, resistance from wind, waves, shallow water and steering is added. The shallow-water resistance is calculated from the relation between the resistance at infinite water depth at speed V and the corresponding speed yielding the same resistance of finite water depth given by Lackenby (1963).

\[
\frac{\Delta V}{V} = 0.1242 \left( \frac{A}{h^2} - 0.05 \right) + 1
\]

\[- \left( \tanh \frac{g \cdot h}{V^2} \right)^\gamma ; \nu \frac{A}{h^2} > 0.005 \quad (2)\]

where:
- \(\Delta V\) : Is the speed loss compared to infinite water depth.
- h : Water depth.
- A : Immersed cross-sectional area of the ship.
- g : Gravitational constant.

This formula was derived from Schlicting's (1934) graphical method for predicting shallow-water resistance.

Opposed to the approach used by Marks, Goodman et al. (1968) and more recently Calvert et al. (1991) and Andersen (1988), the wave resistance model in the EVP is derived from the huge amount of work done to calculate in a direct way the added resistance in waves. Contributions to this effort are among others given by Faltinsen (1980), Wada & Baba (1987), Salvesen (1975), Hearn, Tong and Lau (1987), Naito, Nakamera and Nishiguchi (1987). The wave-induced added resistance is divided into two contributions each describing different ship-wave interactions. One contribution arises from the fact that small waves compared to dimensions of the ship are reflected by the ship hull.
Thus, the energy of the wave train is reflected resulting in a corresponding force acting on the ship.

The second contribution is related to the induced relative motions of the ship. The relative motion of the ship generates waves which are radiated from the ship. This dissipation of energy is directly connected to the loss of speed of the ship.

Since resonance between especially the pitch motion of the ship and the incoming waves may occur and hence the amplitude of the relative motions become huge, the speed loss associated with this phenomenon may be very significant. Figure 6 illustrates the nature of the two types of wave resistance.

The wind resistance is calculated from measured wind-resistance coefficients. An example of the wind-resistance coefficient for a bulk carrier is given in Figure 7.

\[ P_s = V_s \cdot \frac{R}{1-t} \frac{1}{\eta_o \eta_R \eta_s} \]  

\( V_s \) : The ship speed.  
\( t \) : The thrust-deduction coefficient.  
\( R \) : Total resistance.  
\( \eta_o \) : Open-water efficiency of the propeller.  
\( \eta_R \) : Relative rotative efficiency.  
\( \eta_s \) : Shaft efficiency.
To convert the brake horsepower into fuel consumption a relation for the specific consumption has to be available. Usually, the specific consumption or economical efficiency of the engine $kJ_{out} / kJ_{in}$ is supplied with the documentation for the engine. Figure 8 shows a typical diagram valid for a two-stroke diesel engine. By making corrections for the specific gravity and calorific value of the actual fuel the consumption may be calculated directly in kilograms and hence the fuel cost calculated directly by multiplying by the fuel price, i.e. $/\text{ton}$.

In addition to the calculated loading of the engine expressed in terms of the number of revolutions on the engine and the mean pressure (function of fuel consumption and RPM) the load limits of the engine have to be calculated to check whether the engine is overloaded or not. A typical set of load limits for a two-stroke diesel is shown in Figure 9. The load limits are normally determined by 4 or 5 curves in the diagram. 1) The max. RPM line, 2) the maximum mean pressure, 3) the overload limit at RPM variable mean pressure determined by the pressure of the scavenging air, and 4) a minimum continuous RPM, and in some case also a 5) maximum allowable power output - an owner's horsepower instruction -.

Ship Motions. Response amplitude operators for the motion characteristics are calculated for the ship in different loading conditions. Interpolation in these pre-calculated values is made to estimate the RAO's for the actual loading condition.
The motion characteristics relevant for the ship-routing problem will be the accelerations at the perpendiculars, relative motion of forward perpendicular for determining the probability of shipping green water on the deck, and the roll angle. If prediction of propeller racing would be applicable, also the relative motion at or near the aft perpendicular should be included.

The RAO's are calculated using strip theory c.f. Faltinsen (1988).

**Optimization Algorithm.** A method for reaching the route - track and speed profile - that minimizes the overall cost of the route is described in the following. A more complete derivation of the method can be found in Scheller (1989). The method will take into account restriction on the route so that travelling over land, travelling at a speed that will require exceedance of the installed horsepower, etc., will be avoided.

**Track Optimization Algorithm.** The route is presented by a number of waypoints each describing a position and a time of arrival to the waypoint, c.f. Figure 10. The ship is assumed to travel a constant speed and course between the waypoints.

![Figure 10. Definition of Track Segments.](image-url)

With the route being uniquely defined by the waypoints, and the overall costs being a function of the route, the overall cost of the route can be regarded as a function of the waypoints:

\[ T_c = (x, y, t) \]

This is the function to be minimized, while observing a set of constraints. Constraints can be any of the following:

1. Waypoints, fixed in time and position. That is e.g. arrival at a certain harbour at a certain hour. This constraint is only relevant for defining start and end points of the route.
2. Ordinary waypoints. That is points that are fixed in position but not in time, e.g. travelling through a narrow passage at a non-fixed hour.

3. Time-fixed points. All points must have at least one of its parameters fixed, if agglomeration is to be avoided. Therefore, graphically non-fixed points have to be time fixed.

4. Geographical restrictions, e.g. islands or seasonal load-line zones.

5. Restrictions on the route due to power limitations, ship responses, etc.

It may not immediately be obvious that Condition 5 "Restrictions on the route due to power limitations . . ." is a limitation on the optimization in terms of a constraint. However, by prescribing a very high cost associated with exceeding the power limit, roll limit, limiting number of slam, etc., the constraint will be treated in a "soft" manner. The softness of the constraint is determined by the steepness of the associated cost function. Exceedance of the limits will be paid for by an additional cost, which if sufficiently high will prevent the route from being cost effective unless exceedance is avoided.

Segmented Length Strategy. The Track Optimization Algorithm as described in the preceding section optimizes the position / time of arrival of a number of waypoints that defines a route. It is, however, possible to change the number of segments on the start track by placing additional waypoints along the track. This will not effect the start track, but may influence the optimization.

It is evident, that the more waypoints there are on the optimized track, the more complicated the optimized track can be. A complicated route converging against continuous change of speed and course, will be able to reflect changes in the weather along the route better than the simpler route. Continuous changes in speed and course are, however, inconvenient to the captain (and do not reflect the discrete nature of the weather data base), so a weighing between gained cost reduction and route complication has to be done.

This can be done by optimizing a given start track, record the cost, then double the number of segments by placing additional waypoints halfway between each two original waypoints and finally, redo the optimization. If the relative cost reduction is less than say 10⁻³, the route complication cannot be said to be outweighed by the cost reduction.
If, however, the cost reduction is big enough, the entire process can be redone using the new track as a start track.

This procedure can be refined by taking into account that segment length do not need to be constant over the route. If a segment is defined by waypoints A and B, the additional waypoint C halfway between A and B can be constructed. If the route now is optimized, transferring A, B and C into A', B' and C', it can be determined whether further refinement should take place by looking at the cost of the original segment defined by A and B and compare it with the sum of the cost of segments A' - C' and C' - B'. Only if the latter is smaller than the former, refinement is to take place.

What remains, is the question of how many segments there are to be on the start track. The factors to take into account are the following:

- Calculation time for each iteration.
- Convergence speed.
- Numerical span of the problem space.

Fortunately, all three factors lead to the conclusion, that the start track should have as few segments as possible. The reason will be described here.

Calculation time for each iteration is clearly influenced by the number of segment. Although calculation time is not proportional to the number of segments, if the cost rates are numerically integrated over the segments to obtain the cost functions, the amount of geometrical operations is reduced, if the number of segments is decreased.

Convergence speed is influenced by the number of segments for two reasons. First of all more segments will give more degrees of freedom to be optimized, thus making optimization more complicated and increasing the number of iterations necessary in order to find the optimum. Secondly, the "Steves cage" problem increases as the number of degrees of freedom increases, thus not only increasing the number of iterations necessary to find the optimum, but also increasing the risk of not finding the optimum at all. This effect is small, if the strait track is close to the optimized track and increases if the start track is further from the optimized track.

Gradually increasing the number of segments as described, has the benefit that the convergence speed will be much faster if the track had been totally refined from the start.

As explained, the Track Optimization Algorithm always finds the nearest local minimum.
It is interesting, however, that what is the local minimum with one number of segments on the track is not necessarily a minimum with another refinement of the track.

By having the algorithm search as much of the problem space as possible (increasing the numerical span), it should in principle be possible to find the global minimum. Clearly the numerical span will be the biggest, if the start track consist of as few segments as possible, thus increasing the probability of the algorithm finding the global minimum.

Figure 11. Simple Illustration of the Bigger Numerical Span using the Segment Length Determination Strategy than using the Simple Track Optimization Algorithm.

Sea Trial. The EVP has been tested during a single voyage on board the Danish bulk carrier. The test took place in May, 1991 on a voyage from Colombia to Denmark.

After the initial impression made by a lot of computer technology brought on board a ship with no previous experience of computers except a PC, a number of valuable points was high-lighted. These points are compiled as follows:

- Many navigators graduated 10 years ago or earlier, have no experience with computers. Solutions obtained by use of computers are therefore judged with suspicion until adequate training has been given.

- There exists a lack of understanding of the optimization philosophy. This is partly due to the fact that ships not sailing in liner traffic, although they principally have an open time of arrival, very often have to take a dictate on when to arrive, and very importantly the dictate may be given very late on the voyage.
The master’s incentive to do an optimization is very little since he will surely be blamed for a late arrival, but not necessarily credited for a cheap passage. There is not always a complete agreement on the economical aspects in "buying" a safety margin against being late compared to the cost of being late. This is a problem which also has its foundation in the natural scepticism of the validity of the weather report broadcasted to the ships. If the master is not familiar with the theoretical background in the optimization he will not accept its results if they are not immediately acceptable for him based on his own judgement of the possible development of the weather.

Conclusion. A prototype EVP has been developed to a point where it has been shown that voyage planning and optimization can be utilized in an on-board system.

The functionalities of the EVP have proven to be adequate for the purpose. Before an EVP will be used successfully on-board ships it appears to be necessary to develop a common standard for broadcasts of weather information.

Training of the personnel using the system will also be a key issue in the successful introduction of an EVP. The comments about this matter made in Section 6 are of course not valid for all ships, often will the attitude towards such a system be quite different in ships sailing with a tight schedule such as for instance a container ship.

The results obtained from the optimization will of course not be any better than the input given to the system. The major contributor to the uncertainty of the results is therefore the uncertainty of the weather input and especially the wave forecasts. Unfortunately, the development of ocean wave models is pushed to the very limit of what is possible today.

The accuracy of any optimization system is therefore closely connected to the development of such models.

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Vidal, R.V. (1984): "Note on Static and Dynamic Optimization". IMSOR, Danish Technical University, Lyngby, Denmark.
Application of information technology in shipping and communications
N.A. Al-Nakib

ABSTRACT

Since the invention of radio and its subsequent use at sea, there has been constant development in the application of information transfer between ships and the shore, resulting in new maritime communication technology.

The utilization of satellite communications at sea, and in particular the Inmarsat system, has opened-up an avenue for data communications, that in the past was unavailable to either the on-board staff, or the shore-based personnel of the shipping community. This form of information transfer has become applicable to the management of ships, maritime distress and safety functions and direct support to the navigation systems on-board.

By using the Inmarsat system, the larger shipping companies have proceeded towards developing software programmes, which encompass the important aspects of managing their ships when on voyages, and providing easier facilities for direct communications between the technical staff ashore and the ship. This has led to saving time and effort and in the long run has enhanced the profitability of operations. The Inmarsat system also plays an important role in the Global Maritime Distress and Safety System (GMDSS) and supports the applications of electronic charts.

This paper describes development in this field and a future outlook.
IN'RODUCTION

Human ability to communicate information between two points has been measured in relation to the medium used. For most of history communications over distances has involved travel, if use was not made of crude methods of visual signalling by flares, smoke and light. The first milestone in distant communication was reached, when electrical telegraph communication began in 1837. The second milestone was reached when the telephone was invented in 1876; by then there were two completely different but complementary methods of fast communications over distance. The third milestone, which created a large impact on maritime communications, was the invention of radio by Marconi in 1895. Subsequent development of radio communications paved the way for maritime satellite communication systems.

It is doubtful if any new development in recent history has had such a wide-spread effect on Industry, commerce or the general public as the development of the computer. The arrival of the computer may also be considered as another milestone in the annals of communications, and progress of mankind has to a certain extent been measured by how successfully one has been able to communicate with computers and how efficiently they have been made to communicate with one another. Data transmission can be defined as the movement of information in coded form over a transmission system, generally prior to or after processing by a computer. Data communication, however, has a much wider meaning than data transmission and embraces not just the transmission but many other factors involved in controlling, checking and handling the movement of information in a communications-based computer.

This blend of computers and communications is now taken for granted and has gradually crept into the maritime industry. The communication systems used play an important role in the quality and speed of the data transmitted and received. Initially transmission over cable facilitated the development of information transfer on land. However data-via-radio has not led to advancement of the process and subsequently the mariner has not been able to utilize its technology to the fullest extent. Radio (utilizing ground waves or ionospheric propagation) has never been a good medium for the transfer of data. The quality of communication is not very high and subsequently the bit error rate is also very high. This led to a situation where a repetition of the transmitted data was always necessary in order to eliminate the error; furthermore the repetition was so frequent as to produce an uneconomical mode of communication. In certain areas of the world "blind spots" prevented or interrupted data transmission over radio, making it significantly unreliable. A prominent method of low-rate data transmission at sea has been telex-over-radio; difficulties attached to this system are well-recorded. In certain areas of the world some systems of HF data
transmission to ships have been developed, but these are mainly special purpose systems and have not been extended to international use.

Data transmitted on land through cable was gradually developed over the years to attain improved quality, reaching a stage where the bit error rate was almost eliminated by the recent development of optical fibre cables. When data was introduced to satellite communications over the fixed services (e.g., Intelsat), it was an alternative form of transmission media, which provided good quality communication through the use of line-of-sight frequencies (L-Band and Ku-Band). Although satellite data communication may not provide the same quality in comparison to cable, yet the bit error rate (using advanced error correction techniques) is very low indeed and makes it a desirable system of communication.

Inmarsat was established in 1979 and began operating its space segment in February 1982. In the maritime sector, Inmarsat’s purpose is to provide the space segment to improve maritime communication, thereby assisting in improving communications for distress and safety of life at sea, the efficiency and management of ships and maritime public correspondence services and radio-determination capabilities. All these functions, in one way or another, involve the use of data communications between ships at sea and locations on-shore. Therefore, Inmarsat soon embarked upon developing its own range of information transfer systems.

More recently the Global Maritime Distress and Safety System (GMDSS) has emphasized the need for a worldwide communication system to be used for distress alerting, search and rescue operations and maritime safety information. Data transmission over the Inmarsat satellites has provided a facility that satisfies the functional requirements of the GMDSS.

**INMARSAT**

Inmarsat was established as an internationally-owned cooperative to meet the needs of the world shipping community for reliable communications. It was envisaged at an early stage that Inmarsat could, in the future, provide a shared satellite system for both aeronautical and land-mobile services. Inmarsat has evolved to become the only provider of global mobile satellite communications for land, sea and aeronautical applications. The headquarters is located in London and the Organization has more than 60 member countries from all regions of the world. Participation in Inmarsat is done on two levels, namely:

(1) **THE PARTY**: means a State, which has ratified the Inmarsat Convention.

(2) **THE SIGNATORY**: means either a Party or a competent entity (usually a public or private telecommunication organization),
designated by the Party to sign and implement the Inmarsat Operating Agreement, which is attached to the Inmarsat Convention.

Inmarsat is fully financed by its Signatories; the level of investment in the Organization is directly proportional to an individual Signatory’s utilization of the Inmarsat system. In order to function, it has a three tier organizational structure consisting of the following:

- **The Assembly**: composed of representatives of all the Parties, each of which has one vote. The Assembly meets once every two years to review the activities and objectives of Inmarsat and to make recommendations to the Inmarsat Council.

- **The Council**: has 22 members; 18 representing Signatories, or groups of Signatories, with the largest investment shares. Four others are selected by the Assembly on the principle of just geographical representation, with due regards to the interests of developing countries. The Council meets at least three times a year to oversee the activities of the Directorate. During these meetings a Council member has a voting power equal to its investment share.

- **The Directorate**: the permanent staff of Inmarsat comprising about 50 different nationalities working under the supervision of the Director General. The Directorate carries out the day-to-day operations of Inmarsat.

The Assembly forms the political hierarchy, the Council functions as the board of directors and the Directorate implements the decisions and policies of the Council.

**THE INMARSAT SATELLITE SYSTEM**

To provide its services, Inmarsat uses its own Inmarsat-2 satellites and leases the Marecs B2 satellite from the European Space Agency, maritime communications subsystems (MCS) on several INTELSAT V satellites from the International Telecommunications Satellite Organization (INTELSAT) and capacity on three MARISAT satellites from COMSAT General of the United States. The system is currently configured with operational satellites over four Ocean Region Areas as follows:

<table>
<thead>
<tr>
<th>Ocean Region</th>
<th>Satellite</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic (W)</td>
<td>Marecs B2</td>
<td>55.5 W</td>
</tr>
<tr>
<td>Atlantic (E)</td>
<td>Inmarsat-2 F2</td>
<td>15.5 W</td>
</tr>
<tr>
<td>Indian</td>
<td>Inmarsat-2 F1</td>
<td>64.5 E</td>
</tr>
<tr>
<td>Pacific</td>
<td>Inmarsat-2 F3</td>
<td>178 E</td>
</tr>
</tbody>
</table>
Ship Earth Stations (SES) transmit and receive signals to and from the shore via the satellite; Coast Earth Stations (CES) interface the satellite traffic with the national and international networks and each Network Coordination Station (NCS) acts as a switch operator, assigning, controlling and monitoring the traffic channels between the SESs and the CESs. At least one NCS is used for each Inmarsat system in each ocean region area.

NCSs of the different ocean regions are linked into a central Network Control Centre (NCC), which monitors, coordinates and controls the communication networks. The satellites are operated from the Satellite Control Centre (SCC), which performs the functions of station-keeping, telemetry, tracking and command. Both the NCC and SCC are located at Inmarsat's headquarters in London. Monitoring, control and coordination of the systems are carried out over an international network of communications to tracking stations, coast earth stations and network coordination stations.

Figure (1) The Inmarsat Network

- - - - NCS common channel
- - - - - Request and assignment
- - - SES-CES message channel
- - National / international telecommunication landlines

NCS Network Coordination Station
CES Coast Earth Station
SES Ship Earth Station

Shore - based subscriber
THE INMARSAT COMMUNICATION SYSTEMS

Inmarsat presently has two systems in operation, namely:

1) The Inmarsat-A System: The first operational Inmarsat system which provides direct telephony and telegraphy capabilities. Services offered over this system are telephony, telex, facsimile and data transmission. Distress alerting is also a main function of the system for maritime users, providing Distress Priority on both telephony and telex as well as having a Distress Message Generator capability for telex only.

2) Inmarsat-C System: A digital message store-and-forward system, which has received wide acceptance for the Global Maritime Distress and Safety System. Inmarsat-C does not offer a voice circuit. Baseline services provided over this system are generally message and data. The system also supports the Enhanced Group Call (EGC) function, which allows sending a message to virtually an unlimited number of predesignated ship earth stations.

Inmarsat is currently developing three new systems, namely:

1) The Inmarsat-B System: The digital successor to the Inmarsat-A system. It is based on modern digital technology in order to achieve more efficient utilization of satellite power and bandwidth resources, which will potentially reduce communication charges. In addition to voice and telex services, Inmarsat-B offers a wide range of data and facsimile services, user facilities (e.g., direct dial-in from shore) and safety-related features.

2) Inmarsat-II System: This system is being developed in parallel with the Inmarsat-B system and its design is based on low-cost, lightweight ship earth stations offering voice and low speed data/facsimile.

3) Inmarsat-E System: In conjunction with the Global Maritime Distress and Safety System, the Inmarsat-E system employs Emergency Position Indicating Radio Beacons (EPIRBs) transmitting on the L-Band frequency of the Inmarsat satellite. The system allows EPIRBs and coast earth stations uninterrupted access to the satellite to give fast distress alerting. The EPIRB may also be linked to the ship or other navigational systems to provide details of the ship course, speed and position.

INFORMATION TRANSFER THROUGH THE INMARSAT SYSTEMS

INMARSAT-A

The Inmarsat-A system presently provides automatic dial-up two-way telephony and telex to more than 13,000 ship earth stations. The Inmarsat voice grade channels can also be used
successfully for facsimile and data transmission at channel speeds up to 9.6 k.bits/sec. The data communication software and hardware required for this purpose is readily available, but may vary depending on specific requirements, such as average data volume to transmit, number of calls per day etc.

In general the basic on-board ship data requirements are as follows:

- **A COMPUTER**: that will process the information and run the programme.

- **APPLICATION SOFTWARE**: that will contain the data programmes selected by the shipping company.

- **VOICE BAND DATA MODEM**: that will interface the computer with the ship earth station for data transmission (handshaking).

- **COMMUNICATION SOFTWARE**: that will provide the transfer protocol in order to maintain fast and simple operation and ensure end-to-end data integrity.

- **INMARSAT SHIP EARTH STATION**: That will perform the link with the coast earth station.

The requirement on shore (e.g., at the shipping company) will be similar to that required on-board, replacing the ship earth station with the public switched telephone network (PSTN) or a direct leased line with the coast earth station.

![Figure (2) Data Transmission Via Satellite](image)

Any PC

used with

Serial port speed 19.2Kbps,
Hardware flow control

Modems:

<table>
<thead>
<tr>
<th>Modem</th>
<th>Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>V.22bis</td>
<td>less than 1 Kbytes</td>
</tr>
<tr>
<td>Courier (HST)</td>
<td>less than 50 Kbytes</td>
</tr>
<tr>
<td>V.32</td>
<td>more than 50 Kbytes</td>
</tr>
</tbody>
</table>

Inmarsat-A SES

Cost Earth Station

Telephone line

PSTN

(Public Switched Telephone Network)
Add-on options to the above facilities are available either to improve the data transmission functions or to provide other functions; they include:

-DATA COMPRESSION SOFTWARE: that will significantly increase the transfer rate and consequently save time and money.

-PHOTO TRANSMISSION EQUIPMENT: available for both Macintosh and IBM PC compatible computers; they allow display of live video on the computer screen, to freezing of a frame, compression and transmission as a data file via a modem and a ship earth station.

INMARSAT-A APPLICATIONS

-VESSLE MANAGEMENT:

A wide range of management tools exist that can assist the ship owner in the operation of his vessels. In general, lists, statistics and monitoring data are a basic requirement for information exchange between the shore and the ship. This may include stores and supplies, staff records and payrolls, cargo operations, stability and damage information, maintenance, monitoring machinery performances and supervising running costs.

Those applications provide an improved ship management process, utilize an efficient communication system at reduced cost and enhance the safety of the vessel. The use of such features can motivate the crew on-board, resulting in an increase in their performance standards.

-OPERATIONAL AIDS:

Photo transmission via satellites has been achieved through both analogue and digital equipment for transmitting and processing high resolution colour photographs, in a very short time. This technology can benefit the engineer on-board, the maritime insurance sector, cruise vessels marketing, maritime law enforcement agencies, marine scientists, off-shore operators and fishery experts. For similar purposes still video applications have also been demonstrated, where the video signal coming from a video camera can be manipulated by the computer as an ordinary graphic. Zooming, resizing, rotating the picture, changing its colours, creating contrasts or even using special effects are possible modes of operation for specialized applications.

Another operational aid, available over the Inmarsat-A system is the differential GPS position correction. Purpose built receiving equipment, interfaced to the Inmarsat-A terminal, decodes the correction data and applies the same to the ships GPS measurements. Such an application contributes to navigational accuracy.
-FUTURE APPLICATIONS-

Inmarsat is now starting to introduce data transmission service at 64 k.bits/sec. Multiplexing will become a feature of the service providing additional applications, and in particular allow a ship to support several simultaneous voice, fax and medium speed data calls. This will give the ship an opportunity to lower its own communication costs whilst increasing the volume of communications. With 64 k.bits/sec, a two way video system will become feasible to support applications like video conferencing and video-phones. The 64 k.bits/sec. services may become a requirement on-board passenger and ferry ships.

INMARSAT-C

Since Inmarsat-C is a digital messaging system, all its operations are conducted on a data transmit and receive basis. In general, ship earth stations manufactured nowadays will incorporate the computer, the application software and will not require a modem. On the coast earth station side the data signal is stored then forwarded through telex lines, Packet Switching Digital Networks (PSDN), or telephone lines to a telex terminal, personal computer and printer, or facsimile terminal, as appropriate. In respect of facsimile, the coast earth station will initiate the fax message to the end-user after receiving it from the ship in the message store-and-forward system. Facsimile in the Inmarsat-C system operates in one direction only, i.e., in the ship-to-shore direction.

Figure (3) The Inmarsat-C Communications System
INMARSAT-C APPLICATIONS

-ENHANCED GROUP CALLS (EGC): An advanced group call facility supported by the Inmarsat-C system, which allows a land-based centre to broadcast messages to selected groups of ship earth stations, which may be located anywhere within an ocean region.

Two EGC services are available:

(1) SafetyNET™: This service provides an efficient low cost means of transmitting Maritime Safety Information (MSI) to vessels at sea. MSI may include navigational warnings, weather warnings and forecasts, rescue coordination communications (shore-to-ship), ice hazards and other urgent warnings.

(2) FleetNET™: This service is designed to allow authorized information providers such as commercial subscription services, shipping companies and governments to broadcast messages to selected groups of ship earth stations. Typical information provided includes fleet or company broadcasts, news broadcasts, commercial weather services, market quotations and government broadcasts to its own vessels.

-DATA REPORTING: The data reporting protocol is optimized for the transmission of bursts of short packets of data. In addition to the normal format of the report, information may be included in a further compressed form by the use of Macro-Encoded Messages (MEMs). These use unique binary codes to represent a predefined text. An example of the MEM can be for instance a small number of bits to represent "The vessel has been exposed to weather damage".

Typical ship reports may include sailing plan, position report, deviation report, arrival report, departure report, shipping company position report and weather data report.

-POLLING: Operates in the same manner as data reporting, but in the reverse direction. Organizations ashore such as shipping companies and control centres may send polling commands to either individual or groups of ship earth stations. The polling command may include instructions to send report(s) immediately, at random basis, or at pre-set regular times. Polling may be used to trigger information flow if the Inmarsat-C terminal is being used to monitor onboard operations (e.g., machinery or navigational monitoring).

-DATABASE APPLICATIONS: Inmarsat has developed an evaluation pack consisting of a database and an Inmarsat-C interface. Its main feature is that it implements a "Standard Query Language (SQL)". This language, is in fact a set of commands supported by several database products from different manufacturers. This means that a command written for one product will have the same syntax for another database. A
service provider transmitting information to its subscribers would therefore not have to worry about the hardware or the software that customers are using aboard their ships. Such databases may include details on ship management, spare parts tracking, maintenance and inspection, medical chest management, customs and immigration rules, port information, notices to mariners and others. Update of the database can be continuous, in accordance with the service providers’ conditions.

-TOUCH SCREEN APPLICATIONS: Inmarsat has also developed a demonstration package enabling a user aboard ship to send handwritten messages via an Inmarsat-C terminal. A computer using the package will require an interface and a compatible PC, and features a touchscreen and an electronic pen. Basically, what the user has to do is handwrite the name of the vessel, (the computer translates the handwriting into computer data), tick a few boxes on the screen with the metallic stylus, write some additional comments and click on the "send" button. This application removes the barrier between people. The built-in handwriting recognition algorithm presently supports a limited number of languages.

FUTURE TRENDS

The present maritime communication systems over satellites have enabled an exciting application process, with a focus on distress and safety, proper ship management, aid to the navigation system on-board and facilitation of shipping. The future is even more exciting; the development of digital terminals, new hardware and software computer facilities and increased on-board automation will lead to new applications that are bound to enhance the future of maritime satellite communications.

Some of the ideas that are being considered for the future have included the following:

(i) The development of Wide Area Networks (WANs) providing added-value services such as electronic mail, on a global basis.

(ii) Integrating the maritime mobile system with on-shore cellular networks.

(iii) Increased videophones and image transmission with an integration of those services into the wide area networks.

(iv) Advanced computer interface (e.g., voice input for Inmarsat-C and development of the touchscreen computer application).

(v) Group 4 facsimile with colour and high speed.

(vi) Use of satellite communications to aid the automated operations of ships.
IN CONCLUSION, it has been shown that maritime satellite communications have created an impact resembling the opening of a door, through which new technologies are emerging, to aid the shipping community. A number of shipping companies are structuring their ship management systems on the use of satellite communications, to enhance operations and to save time and money. The GMDSS has also identified reliance on the Inmarsat system within its coverage areas, which account for 95% of the world total water surface area, where the majority of ships operate.

Maritime satellite communication provides resolution to a number of problems that were encountered through the use of conventional maritime communication methods. In fact, with those earlier methods, a saturation limit has been reached, beyond which it was difficult to generate new maritime communication technologies. With satellite communication, however, the modern era of maritime communications is just beginning. Future developments offer many exciting applications to the ship staff, owners and managers and will draw them together causing the shipping industry to become a compact unit.
REFERENCES


SUMMARY

A comparison will be made of safety in aviation and shipping with respect to accidents and technical causes. Legislative requirements and regulations are intended to ensure a safe operation, by satisfying requirements with respect to reliability and maintainability during design, manufacturing and operation. An overview will be given and a comparison will be made of the requirements with respect to maintenance aspects in aviation and shipping. Specific attention will be paid to the methods applied in aviation, to develop a cost-effective preventive maintenance concept in order to ensure a safe operation by adhering the inherent reliability level of the aircraft and its systems. By practical examples, it will be shown that these methods are also applicable to ships and shipsystems.

SAFETY IN AVIATION AND SHIPPING

Safety can be expressed statistically in absolute and relative figures of fatal accidents. In aviation these figures are annually presented by international bodies as the International Civil Aviation Organization (ICAO) by the ICAO-Bulletin and by the Civil Aviation Authority (CAA) by the CAA World Airline Accident Summary. In regular civil aviation (excluding GOS and China) in absolute terms about 20-30 fatal accidents per annum take place resulting in 600-800 passengers killed, with about 10,000 aircraft in service. In relative terms, flight safety is normally expressed in the number of passenger deaths per 100 million passengerkilometer or per 100,000 aircraftkilometer. In these terms, flight safety has been increased considerably over the years as is shown in fig. 1.

With respect to the causes of fatal accidents, some statistics are available.

<table>
<thead>
<tr>
<th>Cause</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Factor HF</td>
<td>51%</td>
</tr>
<tr>
<td>Technical T</td>
<td>14%</td>
</tr>
<tr>
<td>Combination HT and T</td>
<td>14%</td>
</tr>
<tr>
<td>Weather Conditions W</td>
<td>7%</td>
</tr>
<tr>
<td>Combination HF and W</td>
<td>8%</td>
</tr>
<tr>
<td>Sabotage and others</td>
<td>6%</td>
</tr>
</tbody>
</table>

The Human Factor is in aviation the major cause of accidents. Technical causes account for about 20% of all fatal accidents [1]. It is in this respect were maintenance has to make its contribution to prevent failures of critical systems.
In shipping, accident statistics are published by Lloyd’s Register of Shipping [2]. As is shown in fig. 2, the present level of fatal accidents amounts to about 30 per 10,000 ships per year by about 75,000 vessels and an annual figure of 600-4000 lives lost. This number of lives lost is of about the same order as in civil aviation. The relative number of accidents expressed as the annual accident rate, shows also in shipping a diminishing trend, as is shown in fig. 2. An analysis of the (211) accidents in 1989, of which 32% recorded some loss of lives, reveals a figure of about 25% of the accidents caused by technical reasons. This emphasizes the need to consider the reliability aspects during design and the establishment of a preventive maintenance program in order to keep the reliability at the required level.

LEGAL REGULATIONS AND ITS RELATION TO MAINTENANCE

Ensuring safety is a concern of the manufacturer, user and the government. The role of the government is to safeguard safety under commercial pressure. In aviation the governmental responsibilities in general and with respect to various aspects are laid down in the Convention of Chicago and its Annexes. E.g. in Annex 8 the Airworthiness of Aircraft. The actual legislation however, is a national responsibility, laid down in laws and regulations. In the Netherlands: the Aviation Law, Aviation Supervision Regulation, Airtransportation Regulation and Aviation Calamity Law. The national regulations often refer to regulations of the authorities of the large aviation countries as the Federal Aviation Authority (FAA) of the USA and especially to the Federal Aviation Regulations (FAR) of which the FAR 25 lays down the airworthiness requirements for regular passenger aircraft. Presently, the European countries have established their own regulations laid down in the Joint Airworthiness Regulations (JAR). These regulations are regularly updated as a result of new developments and of accident investigations. The Aviation Authority is responsible for the supervision and certification of companies, products (aircraft), services (maintenance), persons (certification), training and operation. The airworthiness regulations are establishing requirements for the design, manufacturing and maintenance of aircraft, with respect to aircraft performance and characteristics, aircraft construction, aircraft equipment and propulsion and to maintenance. In the design stage requirements are stated for aircraft structure and its resistance against load, fatigue and corrosion and the possibilities and requirements for structural inspection. For aircraft systems requirements are to be fulfilled with respect to reliability and fault indication. During production requirements need to be satisfied regarding recording of process and product data, inspection and (functional) testing. Each new aircraft type will get a type certifi-
cate by which its airworthiness is proven by documented argu-
gumentation. Each individual aircraft will get its certificate of airworthiness, which need to be extended annually by showing that all required maintenance has been satisfactorily performed. With respect to maintenance it is required "that the aircraft is maintained in accordance with an approved maintenance programme". "This maintenance programme must be reviewed annually for continued validity in the light of operating experience".
These two requirements will be subject of discussion in the next paragraph.

In shipping, legislative and other requirements are put by:
Classification Societies (class requirements)
National Authorities (flag requirements)
International Authorities (global requirements).
To be classed, a ship has to comply with Classification Societies' Rules and Regulations. The class is also required by Insurance Companies for insurance purposes. The ship must also comply with the laws of the country in which it is registered, to fly the national flag. Major International Conventions (for ships sailing international waters) are:
International Convention for the Safety of Life at Sea-SOLAS (safety)
International Regulations for Preventing Collisions at Sea (sailing)
International Load Line Convention (strength and sea-worthiness)
International Convention for the Prevention of Pollution from Ships

The ship must also comply also with other, as for example, Panama or Suez Canal's requirements when sailing these waters. National Authorities require usually that the International conventions are met. Furthermore, any special requirements, exemptions or specific particular requirements are specified in national laws. For example, in the Netherlands these are:
Schepenwet, Schepenbesluit 1965
Richtlijnen van de scheepvaartinspectie
Uitwateringsverdrag 1966
Schepelingen besluit
Wet op de zeevaart-diploma's.
Classification is a representation by the Classification Society (e.g. Lloyds Register of Shipping, American Bureau of Shipping, Det Norske Veritas, Germanischer Lloyd) as to the structural and mechanical integrity for a particular use or service according to its Rules and Regulations. The ship, if built according to these standards, receives a Classification Certificate, which ensures a definite standard of strength and quality. The ship's structure, machinery and equipment are during operation checked periodically for the attestation of the Class.

The Rules and Regulations are developed by the international
maritime community including naval architects, marine engineers, shipbuilders, engine builders and by other technical and scientific personnel associated with with the maritime industry.

Maintenance considerations during the design stage are implicit in the standards laid down for ship construction. The most explicit standards concerning maintenance, are reliability issues. These concern major ship functions and systems supporting these as the propulsion plant, the steering machine, the power (electricity) plant, boiler arrangements and safety systems (hazard prevention, detection and fighting). Major ship plans concerning these critical functions are continuously reviewed during design.

During fabrication and outfitting, materials are tested and the construction of the vessel is supervised both by the Classification Society and the designer to meet the quality set in the Rules and Regulations. Before delivery the vessel is extensively tested (reliability demonstration). These trials prove the vessel is performing as stipulated in design documents, which comply with the Rules and Regulations.

When the ship is put into operation, the minimal maintenance requirements are laid down in the Survey Program, requested for the attestation for the Class. Surveys represent a periodical check of vessel's machinery's and equipment's condition. However the ship operator is encouraged to implement a specific maintenance concept (preventive, condition based maintenance) if service experience or a systematic analysis, based on sound engineering principles, shows that overall safety and strength standards as specified in the Rules and Regulations, are met.

DEVELOPMENT OF AN INITIAL MAINTENANCE PROGRAM: ORGANIZATION

The organisation for the initial maintenance program for an aircraft is shown in fig. 3.

A Maintenance Steering Committee (MSC) is organized, consisting of engineering managers from the (original) manufacturer(s), from the "launching operators" and representatives of the regulatory authorities from the countries of the launching operators. In Maintenance Working Groups (MWG) for the different aircraft systems, the actual work is done, coordinated and reviewed by the MSC.

This results in a Maintenance Program Proposal (MPP). This MPP is subject of review in the Maintenance Review Board, chaired by the Regulatory Authority. The review by the MRB is especially directed towards safety items and the MRB recommendations are mandatory.

The result is the MRB document which is included in the MPP, resulting in the Maintenance Planning Data (MPD) document. The MPD form the basis for the Maintenance Manual, to be produced by the manufacturer. The MPD will be adjusted against the typical utilisation pattern of the aircraft by the operator, within the limits of the stated maintenance (interval) re-
requirements.
The motivation and assumptions for the adjustments are laid down in the Maintenance Planning Substantiation (MPS) for approval by the National Regulatory Authority and for future reference purposes. The updated MPD is referred to as the Engineering Specification Manual (ESM). From the ESM the jobcards for the maintenance execution will be derived.

DEVELOPMENT OF AN INITIAL MAINTENANCE PROGRAM: MSG-3 METHOD

The method as developed in aviation for the development of an initial maintenance program will now be described. The method is applied by members of the maintenance working groups (MWG) and will result in the maintenance program proposal (MPP). It will also be used by the MRB review and for the maintenance program substantiation by the operator. This method, as developed since the early seventies, is known as the Maintenance Steering Group (MSG-3) method [4]. This method is sometimes also referred to as Reliability Centered Maintenance (RCM).

The purpose of the maintenance program is to maintain the inherent safety and reliability levels of the equipment. The method will be described and illustrated by examples from a ship system. This is to illustrate the use of this method in the development of an initial maintenance concept for a vessel.

The first step is to decompose the object into separate items, normally components or in aircraft terms Line Replaceable Units (LRU’s). In aviation a standard system-breakdown is used by distinction into systems, subsystems and components. For a vessel, its functions will be broken down into systems as indicated in fig. 4.

A system can be functionally decomposed into subsystems. As an example in fig. 5, the Fuel Oil Service System 8.3 in fig. 4, is broken down into its constituent components. A description of this system by means of the SADT method [3] will show the functional interdependency of the components. This will be helpful by the determination of the effects of functional failures of component(s)(functions) on system level. All inputs and outputs may be quantified.

All components and its failure modes identified this way, need to be classified into significance classes. They will be called maintenance significant items (MSI’s). An item is indicated as significant if it:
- could affect safety
- is undetectable during operations
- could have significant impact on the operation
- could have significant economic impact.

For each item will be identified its:
- functions: the normal characteristic actions of an item
- failures: how an item fails to perform its function
- failure effects: what is the result of a functional failure
- failure causes: why the functional failure occurs.

The identification of the significance of each component will
be performed by means of a decision logic diagram, see fig. 6. There are 4 subsequent questions which need to be answered for each functional failure of the item being analyzed.

Question 1: "Is the occurrence of a functional failure evident to the operating crew during the performance of their normal duties?"

The intent of this question is to segregate the evident and the hidden failures.

For each evident failure:

Question 2: "Does the functional failure or secondary damage resulting from the functional failure have a direct adverse effect on operating safety?"

A "YES" answer indicates a safety effect category. In this case maintenance tasks are required to assure safe operation.

Question 3: "Does the combination of a hidden functional failure and one additional failure of a system-related or back up function have a direct adverse effect on operating safety?"

The question takes into account failures in which the loss of the one hidden function (whose failure is unknown to the operating crew) alone does not affect safety; however, in combination with an additional functional failure (system-related or intended to serve as a back up) has an adverse effect on operating safety.

A "YES" answer to question 3 classifies the failure into the hidden safety effect. In case of a hidden safety effect, maintenance tasks are required to assure the availability necessary to avoid the safety effects of multiple failures.

A "NO" answer to question 3 classifies a failure into an hidden economic effect. For these failures maintenance tasks are desirable to assure the availability necessary to avoid the economic effects of multiple failures.

Question 4: "Does a functional failure have a direct adverse effect on operating capability?"

This question is asked for each evident, non-safety functional failure. A "YES" answer classifies the failure as an operational effect. For operational effects maintenance tasks are desirable if the cost is less than the combined cost of the operational loss and the cost of repair.

A "NO" answer to question 4 puts the failure into an economic effect class. Tasks are desirable if the cost of the task is less than the cost of repair.

The next phase in the development of an initial maintenance concept is to identify effective and efficient maintenance tasks. In fig. 7 are stated subsequent questions which need to be answered.

Question A: "Is a LUBRICATION OR SERVICING TASK applicable and effective?". Such a task is applicable if the replenishment of the consumable reduces the rate of functional deterioration.

Question B: "Is the ability to detect degradation of the function by normal OPERATING CREW MONITORING applicable and effective?". Reduced resistance to failure must be detectable and rate of reduction in failure resistance must be predictable.

Question C: "Is the ability to detect degradation of the function by on-aircraft or off-aircraft INSPECTION OR FUNCTION-
NAL CHECK applicable and effective?". Reduced resistance to failure must be detectable and the rate of reduction in failure resistance must be predictable.

Question D: "Is a restoration task to reduce failure rate applicable and effective?". It must be possible to restore the item to a specific standard of failure resistance.

Question E: "Is a discard task to avoid failures or to reduce the failure rate applicable and effective?".

The item must show functional degradation characteristics at an identifiable age and a large proportion of units must survive to that age.

Question F: "Is there a task or combination of tasks which is applicable and effective?"

For each identified task, frequencies and intervals have to be established. These intervals may be derived from prior historical data from previous generation items which shows that a scheduled maintenance task has offered substantial evidence of being effective and economically worthwhile. It may also result from manufacturers testdata which indicate that a scheduled maintenance task will be effective for the item being evaluated.

If there is no prior knowledge from other aircraft systems/powerplants or if there is insufficient similarity between the previous and current systems, the task interval/frequency can only be established initially by experienced working group and steering committee personnel using good engineering judgement and operating experience in concert with accurate data (reliability, redundancy, etc.).

For this reason, an initial maintenance program therefore is of conservative character and needs to be adjusted on the basis of experience gathered during the operational phase.

PERIODIC ADJUSTMENT OF THE MAINTENANCE PROGRAM.

For reasons of periodic evaluation of the effectiveness of the preventive maintenance program, maintenance historical data have to be registered and analysed periodically. This means that all relevant failure data and inspection findings have to be recorded at component level. Especially in situations of a fleet of similar vessels, the time necessary to collect historical data which may become representative for the failure behaviour of the systems and components will not become too long.

For particular systems, Classification Societies are collecting already failure data, which are being used to adjust the inspection rules.

In aviation, the operators are recording, as required by the regulatory authorities, maintenance and utilisation data. Larger operators will report these data periodically by means of a Reliability Monitoring Program. Monthly reports will be generated by which the Mean Time Between Failures per system and each significant component will be graphically recorded over longer periods. If an predefined alert level will be exceeded, investigation of the failure causes will be carried
out and actions taken in order to reduce the failure rate.
Possible action could be the adjustment of the maintenance concept.
Manufacturers play a role by providing operators with data of
MTBF figures of their aircraft against the world fleet average. It means that for this purpose, operators need to provide
the manufacturer with their failure data. An operator is therefore in the position to judge the reliability behaviour of
his aircraft systems and components, against the worldfleet.

Another evaluation an airline will perform, is the evaluation of inspection findings. If nothing is found during a certain
number of inspections, and the MTBF of the systems concerned are not decreasing, the inspection intervals may be extended
by e.g. 10%. In case of safety-items, the manufacturer and the regulatory authorities have to be consulted and need to give
approval. These interval escalation might be extended until experience shows that optimum intervals have been reached. In
practical terms inspection intervals might be gradually extended 3-5 times the initial interval.

Also in shipping, maintenance plays not only a vital role in ensuring the operating safety by ensuring the reliability, maintenance costs are about 15-20% of total operating costs
[5]. Investigations show that preventive maintenance costs are about 85% of these maintenance costs. In ship maintenance, lessons may be learned from civil aviation, by application of
the MSG method in establishing an initial maintenance concept and the adjustment during the operational period by reliability monitoring and analysis and subsequent adjustment of the maintenance program and intervals.
May this lead to further increase of safety at sea and a reduction of maintenance costs by improving maintenance effec-
tiveness.

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STATES, EXCLUDING USSR AND CHINA), 1950-1978

ACCIDENT RATES FOR PASSENGERS ON WORLD SCHEDULED SERVICES (ICAO CONTRACTING
STATES, EXCLUDING USSR), 1971-1990

FIG. 1 ACCIDENT RATE AND LIVES LOST IN CIVIL AVIATION

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Historical ('48-'89) Overview of Accidents in Shipping

Lives Lost by Casualty Category ('84 - '89)

FIG. 2 ACCIDENT RATE AND LIVES LOST IN SHIPPING
MANUFACTURER
MSC

MWG*s

MPP

MPD

REGULATORY
AUTHORITY

MRB

MRB
DOC

OPERATOR

MM

MPS

ESM

JOB CARDS

FIG. 3 ORGANISATION FOR THE DEVELOPMENT OF AN INITIAL MAINTENANCE PROGRAM
<table>
<thead>
<tr>
<th>FUNCTIONS:</th>
<th>SYSTEMS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>0. Containment, Protection,</td>
<td>0.1 Shell</td>
</tr>
<tr>
<td>Accommodation</td>
<td>0.2 Decks</td>
</tr>
<tr>
<td></td>
<td>0.3 Bulkheads</td>
</tr>
<tr>
<td></td>
<td>0.4 Foundations</td>
</tr>
<tr>
<td></td>
<td>0.5 Superstructure</td>
</tr>
<tr>
<td>1. Ship Handling - Propulsion</td>
<td>1.1 Engines</td>
</tr>
<tr>
<td>and Positioning</td>
<td>1.2 Transmission</td>
</tr>
<tr>
<td></td>
<td>1.3 Thrusters</td>
</tr>
<tr>
<td></td>
<td>1.4 Steering</td>
</tr>
<tr>
<td>2. Ship Handling - Deck</td>
<td>2.1 Mooring Equipment</td>
</tr>
<tr>
<td>Machinery</td>
<td>2.2 Anchoring Equipment</td>
</tr>
<tr>
<td></td>
<td>2.3 Stores Stowage Equipment</td>
</tr>
<tr>
<td>Communication and Control</td>
<td>3.2 Machinery Control Equipment</td>
</tr>
<tr>
<td></td>
<td>3.3 Communication Equipment</td>
</tr>
<tr>
<td>4. Ship Handling - Bilge &amp;</td>
<td>4.1 Bilge System</td>
</tr>
<tr>
<td>Ballast</td>
<td>4.2 Ballast System</td>
</tr>
<tr>
<td></td>
<td>4.3 Heeling System</td>
</tr>
<tr>
<td>5. Ship Support - Electricity</td>
<td>5.1 Generation</td>
</tr>
<tr>
<td>Supply</td>
<td>5.2 Distribution</td>
</tr>
<tr>
<td></td>
<td>5.3 Consumers</td>
</tr>
<tr>
<td></td>
<td>5.4 Control</td>
</tr>
<tr>
<td>6. Ship Support - Air</td>
<td>6.1 Air Conditioning and Ventilation</td>
</tr>
<tr>
<td></td>
<td>6.2 Compressed Air Systems</td>
</tr>
<tr>
<td>7. Ship Support - Water &amp;</td>
<td>7.1 Sea Water System</td>
</tr>
<tr>
<td>Steam</td>
<td>7.2 Cooling and Fresh Water System</td>
</tr>
<tr>
<td></td>
<td>7.3 Feed Water System</td>
</tr>
<tr>
<td></td>
<td>7.4 Steam Generation and Transfer</td>
</tr>
<tr>
<td>8. Ship Support - Fuel Oil</td>
<td>8.1 Fuel Oil Transfer and Storage</td>
</tr>
<tr>
<td></td>
<td>8.2 Fuel Oil Treatment</td>
</tr>
<tr>
<td></td>
<td>8.3 Fuel Oil Service System</td>
</tr>
<tr>
<td>9. Ship Support - Lubricating</td>
<td>9.1 Lubricating Oil Transfer and Storage</td>
</tr>
<tr>
<td>Oil</td>
<td>9.2 Lubricating Oil Treatment</td>
</tr>
<tr>
<td></td>
<td>9.3 Lubricating Oil Circulation</td>
</tr>
<tr>
<td>10. Ship Support - Stores</td>
<td>10.1 Stores</td>
</tr>
<tr>
<td></td>
<td>10.2 Workshops</td>
</tr>
<tr>
<td></td>
<td>10.3 Engine Room Tools</td>
</tr>
<tr>
<td></td>
<td>10.4 Other</td>
</tr>
<tr>
<td>11. Ship Safety</td>
<td>11.1 Fire Prevention</td>
</tr>
<tr>
<td></td>
<td>11.2 Fire Fighting</td>
</tr>
<tr>
<td></td>
<td>11.3 Fire Detection</td>
</tr>
<tr>
<td></td>
<td>11.4 Life Support</td>
</tr>
<tr>
<td></td>
<td>11.5 Emergency Electricity Set</td>
</tr>
<tr>
<td>12. Cargo Handling - Care</td>
<td>12.1 Loading and Unloading</td>
</tr>
<tr>
<td></td>
<td>12.2 Conservation</td>
</tr>
<tr>
<td></td>
<td>12.3 Processing</td>
</tr>
<tr>
<td>13. Life Support - Sewage</td>
<td>13.1 Sewage Treatment Plant</td>
</tr>
<tr>
<td></td>
<td>13.2 Sewage Collection System</td>
</tr>
<tr>
<td>14. Life Support - Crew Care</td>
<td>14.1 Food Storage and Preparation</td>
</tr>
<tr>
<td></td>
<td>14.2 Laundry</td>
</tr>
<tr>
<td></td>
<td>14.3 Medical Store</td>
</tr>
<tr>
<td></td>
<td>14.4 Inventory</td>
</tr>
<tr>
<td></td>
<td>14.5 Domestic Water System</td>
</tr>
<tr>
<td></td>
<td>14.6 Recreation and Leisure</td>
</tr>
<tr>
<td>15. Special Functions</td>
<td>15.1 Special Vessels' Systems</td>
</tr>
</tbody>
</table>

FIG. 4 FUNCTIONAL DECOMPOSITION
FIG. 5 SERVICE FUEL OIL SYSTEM
for each functional failure

1. failure evident to operating crew?

yes no

evident failure

2. effect on oper. safety?

yes no

4. effect on operation?

yes no

safety operational economic safety economic effects effects effects effects effects

hidden failure

3. effect on oper. safety?

yes no

FIG. 6 DECISION DIAGRAM FOR COMPONENT SIGNIFICANCE CLASSIFICATION
for each functional failure

A: lubrication or service task applicable and effective?

B: degradation of function detectable by operating crew?

C: degradation of function detectable by on/off aircraft tasks?

D: restoration task to reduce failure rate effective?

E: discard task to avoid failures or to reduce failure rate?

F: combination of tasks applicable and effective?

redesign is mandatory desirable

FIG. 7 SELECTION OF MAINTENANCE TASKS
Reliability techniques to improve the safety of machinery

J.T. Stansfeld

Abstract

Trends in data gathered over recent years indicate increasing reliability in marine machinery. This has been achieved as a result of investment in research and development, improvements in design, manufacturing and production methods and regular feedback from service experience. Improved reliability has led to greater availability and maintainability and these contribute to enhanced safety. The increasing complexity of electrical, control and auxiliary systems and the growing awareness of the effects of external hazards on these systems demands the use of reliability techniques for ensuring their integrity and safety.

The paper describes these techniques for targeting critical areas and outlines some of the difficulties associated with quantification. In spite of these difficulties the techniques have contributed widely to improved safety and brought significant financial benefits in other areas. The assessment of human reliability and systems containing embedded software is discussed including the difficulties of quantifying the reliability of safety critical software.
Introduction

The use of formalised Reliability techniques to achieve Safety and Availability requirements has traditionally been associated with high risk industries, notably Space, Nuclear, Defence and Aviation. The techniques which provide formal evaluation and control methods for what is, after all, good engineering practice were developed in these industries. It is these industries where the development of integrated systems has played a key role in technological advance. The growing trend towards integration of marine systems controlling previously completely separate functions requires similar techniques to be applied in design and evaluation.

As the legal, commercial, technological and environmental pressures placed on sectors of industry associated with transport and manufacture increase, so has the relevance of formalised Reliability techniques in assessing safety within these sectors.

Clearly safety does not depend on reliability alone, it is a function of many other aspects which include design, maintenance and use. System safety does, however, depend directly on reliability. In the first part of this paper a traditional view of what constitutes reliability of machinery in the marine context is presented. The 'reliability' of main propulsion engines is examined through information contained in Lloyd's Register’s database. The paper argues that with the growing use of integrated systems machinery cannot be considered in isolation, broader issues need to be addressed in achieving safety through system reliability. Two aspects in particular which are receiving attention are human and software reliability.

For the purposes of this paper, machinery, is defined as any system containing mechanical, electrical, electronic or software features.

Service Experience

Before discussing the present and future uses of reliability engineering techniques in achieving marine safety requirements, a view of recent trends based on an analysis of Lloyd’s Register’s database is presented.

The sample is taken from data for the main propulsion engines for motor vessels built to Lloyd’s Register Classification between 1975 and 1987 inclusive. Both slow speed engines [with an engine speed of 250 rpm or less] and
medium speed engines [with an engine speed between 251 and 800 rpm] are considered.

The defects considered were those reported by the Society’s Surveyors on installations during their service life to December 1987.

A defect is defined, here, as a machinery failure. Neither the extent nor the severity of the defect is taken into account and consequential damage is not considered where the originating defect is reported. However, the nature of the reporting is such that minor defects are not included in the database.

Defect rates are defined as failures per 100 months service where service is defined as the period in Lloyd’s Register Class. During the period there was a broadly similar number of engines at risk in both categories.

**Annual Defect Rates**

*For Slow and Medium Speed Engines*

![Graph showing annual defect rates for slow and medium speed engines from 1975 to 1987.]

*Figure 1 Service Data*
Figure 1 illustrates a clear trend of decreasing defect rate for main propulsion engines over the twelve year period from 1975 to 1987. The reduction in defect rates is more marked for slow speed engines than for medium speed. It is reasonable to assume that in both cases the trend indicates an improvement in reliability and more importantly for the shipowner an improvement in availability.

It is accepted that these improvements in reliability have been achieved without extensive use of formal reliability engineering methods. They are a result of evolutions in engine design, development, manufacture and operation. Over this period engine ratings have increased steadily, fuel quality has deteriorated and the pressures to increase maintenance intervals and reduce specific fuel consumption have increased. Such significant improvements in availability against this background represent a considerable achievement.

The use of formal reliability techniques in design is not generally worthwhile for individual items of machinery which are a result of steady evolutionary development over a number of years. Where however they do become useful is where the design is novel, where quantified targets have been specified in a contract or where the machinery is part of a complex system. In the latter case the ability to consider the system as a whole and address all conceivable failure events, arising for whatever reason, is an essential part of achieving availability and safety. For novel or complex integrated machinery systems the adoption of well tested formal reliability engineering techniques enables these goals to be achieved by highlighting those features that require attention whether during design, operation or maintenance.

**Availability, Reliability, Maintainability and Safety**

The term Reliability (R) is defined as the probability that an item will perform its required function for a stated period of time under stated conditions. Closely associated with reliability is Maintainability (M) which is defined as the probability that a failed item will be restored to operational effectiveness within a given period of time when the repair action is performed in accordance with laid down procedures. Together, R and M values determine the Availability (A) of an item which is defined as the probability that an item will be available for use when required or as the proportion of the total time that the item is available for use. R is frequently stated in terms of Mean Time Between Failure (MTBF) and equivalently M is stated in terms of Mean Time To Repair (MTTR). In a steady
state $A$ is calculated from: $A = \frac{MTBF}{(MTBF + MTTR)}$.

It is clear that an improvement in reliability will lead to an improvement in availability provided the time for repair is the maintainability is not increased. There maybe a trade off therefore between reliability and maintainability in achieving a desired level of availability.

$A$, $R$ & $M$ are interactive with system Safety ($S$). It is possible to specify in quantitative terms the level of $A,R,M$ or $S$ required. The pressures to achieve required levels of Safety and Availability, originate from:

- Greater public awareness of safety and risk issues - Safety of life
- Greater awareness of the effects of pollution and conservation matters - Safety of the environment
- Higher productivity requirements - Safety of Investment

It is argued that the improvements in Reliability illustrated in Figure 1, which reflect on ship Safety levels, will need to be maintained as systems become more complex with the use of well proven Reliability techniques to highlight critical areas. This observation is based on the rate of increase of implementation of advanced technologies in ship design and control systems - and the ever increasing legislative demands (and financial penalties associated with non-achievement) associated with safety levels.

The safety of a ship depends on a wide variety of systems such as propulsion, steerage, navigation, control, auxiliary power and manoeuvring performing when required and in an expected manner. Clearly the ability of these systems to perform can be described in terms of their reliability and availability and these are a function of the reliability and availability of the individual items that go to make up each system as well as the system design.

The standard, and most efficient, means of achieving Safety and Availability levels in, for instance, the avionics industry is through a pre-determined and integrated $A$, $R$, $M$ and $S$ programme. This approach enables optimisation of effort between the AR&M requirements whilst maintaining safety levels. It also allows for quantitative comparison of different design solutions and identification of potential problem areas. Further, through use of associated Logistic Support Analysis (LSA) methods,
assessment of lifecycle cost and spares inventories can be analytically established.

In the marine context safety has been achieved through adherence to Class Rules, Standards, Codes, Statutory requirements, etc., all of which embody many years of service experience. The approach outlined above involving the establishment of an ARM&S programme is just as applicable to the marine industry and complements the traditional methods employed to date.

The reliability engineering methods which are used to enhance the safety of machinery in other industries, and which are applicable to ship design, operation and maintenance are outlined in this paper.

An integrated ARM&S programme identifies quantified requirements and provides a framework and strategy for achievement and verification of ARM&S goals. It should be noted that all aspects of design are considered e.g. Human Interaction, Mechanical, Electro-mechanical, Electronic and Software. The following provides an abbreviated list of the Reliability techniques that can be used:

- Failure Modes, Effects and Criticality Analysis (FMECA)
- Fault Tree Analysis (FTA)
- Reliability Modelling/Block Diagram (RBD)
- Human Reliability Assessment (HRA)
- Event Tree Analysis (ETA)
- Reliability Allocation
- Reliability Assessment
- Data Recording and Corrective Action System (DRACAS)
- System Hazard Analysis (SHA)
- Reliability Qualification Test (RQT)
- Environmental Stress Screening (ESS)
- Independent Verification and Validation (IV&V)
- Risk Analysis

The first three of these are the most commonly used and their features are described later in the paper. The assessment of Human Reliability is an increasingly important topic and is also outlined. Finally the assessment of software reliability is described.

**Failure Modes, Effects (and Criticality) Analysis (FME(C)A)**

An FME(C)A is a powerful and valuable reliability engineering technique. When applied early in the design lifecycle, it can have major beneficial influences on system design. It considers information on probability and causes of system failures together with information on

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failure detection and isolation capability. Failure mode probability data can be derived from reliability analyses techniques and databases. The criticality aspect of an FME(C)A may be omitted in which case a basic FMEA is performed.

FME(C)A is a systematic "bottom up" process in which potential failures at the component or sub-system level are identified and their effect on the overall system is determined. For each component all possible failure modes are identified. The component is then considered as having failed in each of these modes. The effect of these failures at each sub-system level is then identified and if required a failure rate can be assigned. Each system failure can be seen to result from various possible component failures and these can be grouped together to calculate the probability of system failure. Generally only primary failure modes and their effects on system performance are considered. However, in the case of failure modes leading to latent defects the effect of secondary failure modes may be included and quantified. An example of a typical FME(C)A worksheet is shown in Fig 2.

FME(C)A can be a considerable exercise especially where the system is large, with several failure modes for many hundreds of items. Nevertheless its benefits are proven and in many instances it has identified weaknesses in the design of critical systems or equipment that were by no means obvious. It also has the advantage over other techniques in that it is easy to amend as design changes occur. Computer aids are available to assist in this work and usually are provided with interfaces to other reliability programme tasks.

FME(C)As can be either qualitative or quantitative depending on the application. The qualitative method is used most frequently as a hazard identification technique where the failure modes are critical to safety. The quantitative method involves use of failure rate data and an estimate of the criticality of each component or function. Both approaches are covered in BS 5760, DEF STAN 0041 and US MIL STD 1629.

To ensure the best results an FME(C)A should be carried out by an engineer or team of engineers having a thorough knowledge of the system's design and application. This requires the collection of all the relevant design information including for a quantitative analysis the reliability prediction data.

An FME(C)A may be performed at any system indenture level. Judgement on indenture level is based on cost,
<table>
<thead>
<tr>
<th>ID</th>
<th>COMPONENT</th>
<th>FAILURE MODE</th>
<th>FAILURE CAUSE</th>
<th>LOCAL EFFECT</th>
<th>SYSTEM EFFECT</th>
<th>FAULT LEVEL</th>
<th>FAILURE RATE</th>
<th>FAILURE RATE</th>
<th>COMMENTS</th>
</tr>
</thead>
</table>
| 2.1| HFO bunker tank pump | *Electric power loss to motor | *Fuse/circuit breaker trip  
*Terminal block damaged  
*Brushes worn out  
*Wwindings failure  
*No mains supply  
*Pump control failure | *Pump stops | *No delivery to separator | H | D | H | N | *Standby required (to avoid possibility of engine stoppage) (LRR 5.14.4.1)  
*Alarms on pump failure  
*Alarm /trip on separator |
|    |           | *Mechanical failure | *Fracture of shaft  
*Bearing failure  
*Coupling failure  
*Seal failure  
*Excessive wear  
*Lack of lubrication  
*Vibration  
*Misalignment | *Vibration  
*Noise  
*Pump stops  
*Overheating  
*Oil leakage | *No delivery to separator  
*Fire hazard | H | D | H | N | *Alarms as above  
*Zoning  
*Local fire detection  
*Strainer at pump suction  
*Good operating/maintenance procedures  
*Isolating valves on suction discharge in order that pump may be shut off for maintenance (LRR 5.14.4.4) |
|    |           | *Internal relief valve seized open/leakage / pressure set too low | *Poor maintenance/operation | *Low discharge pressure | *Low oil fuel flow to separator  
*Possible separator failure | N | D | H | N | *Good operating/maintenance procedures |
|    |           | *Internal relief valve seized shut/leakage / pressure set too high | *Poor maintenance/operation | *High discharge pressure | *High oil fuel flow to separator  
*Possible separator failure | N | D | H | N | *Good operating/maintenance procedures |
| 2.2| Fuel oil separator | *Electric power loss to motor | *As for 2.1 | *Separator stops | *No delivery to fuel oil service tank | H | D | H | N | *Loss of separator water seal alarm (LRR 6.13.3.14.1) / trip.  
*Refer to separator manual for standard alarms. |
|    |           | *Mechanical failure | *As for 2.1 | *Vibration  
*Noise  
*Separator stops | *No delivery to fuel oil service tank | H | D | H | N | D = DANGEROUS, H = HAZARDOUS & N = NEUTRAL |
effectiveness and reliability design knowledge. For a new
design where the effects of failure are serious and may be
safety critical, analysis should take account of all the
failure modes of all components. However it might be
appropriate to consider functional failure modes of sub
assemblies when these are based on existing and proven
designs.

The FME(C)A is also useful in preparing diagnostic
procedures and checklists since the likely causes of
failure symptoms can be traced back using the FME(C)A
results.

It also provides a record of design assumptions,
derivations of maintenance schedules, inspection procedures
e tc. related to critical items.

An FME(C)A serves to identify system failure effects and as
such can provide input to Fault Tree Analyses. They are,
in a sense, complementary processes.

Fault Tree Analysis

In contrast to the bottom up approach of the FME(C)A Fault
Tree Analysis is a top down approach starting with a system
fault called a top event. A logic tree (Fig. 3) is
constructed using combinations of AND and OR gates to
represent all possible combinations of failure and events
that can lead to the top event. Failure data in terms of
frequencies of occurrence of the base events and
probabilities of occurrence of each branch of the tree
allow calculation of frequency of occurrence of the top
event. Each system failure mode is represented by a path
through the tree from top to bottom and is known as a
cutset.

Combinations of the same base events may occur in several
cutsets however the most important cutsets, known as
minimal cutsets, are those in which the minimum number of
unique base events are present.

As for the FME(C)A the FTA is of most use during design and
pre-production stages. Fault trees for complex systems can
become very involved but excellent programs are available
for their production and identification and quantification
of the minimal cutsets.

FME(C)A and FTA are thus complementary methods for
modelling a system's reliability. Both techniques can be
useful in planning maintenance activities whether for
scheduled maintenance, inspection schedules or for
designing condition monitoring schemes.
Top Event occurs if there is an input from either branch.

**Figure 3** A Typical Fault Tree
Reliability Modelling/Block Diagrams

An essential part of an ARM&S programme is the development of reliability models. These mimic the function of a system from a reliability standpoint (Figure 4). The system is represented as a number of functional blocks on a Reliability Block Diagram (RBD) which are interconnected according to the effect of each block failure on the total system. It is not necessarily the same as a functioning schematic diagram for a system. For complex systems with many interactions construction of the RBD can be quite involved. However, as for FME(C)A and FTA extensive software support tools are available.

Construction of the RBD is made easier if an FMEA has been carried out. Since each failure mode is considered in relation to its effect on the system output. The mathematics of block diagram analysis are beyond the scope of this paper but it can be seen that series and parallel arrangements may be used to allow for the A & B and A or B failures to be modelled. In defining the blocks the function of each block should be clearly identifiable and should contain the maximum number of components in order to keep the diagram simple.

For safety critical functions, contractual, legislative or other specified values for safety can be allocated to each block of an RBD using the linkage between FMEA, FTA and block identification. Software tools are frequently used to achieve reliability allocation. When this has been completed, each part of the system is reviewed using reliability prediction techniques for compliance with reliability requirements. Reliability prediction techniques for electronic and electro-mechanical systems are well established. Mechanical failure mode and rate data are usually derived from company databases of the type that Lloyd's Register maintain. Since these techniques are used to identify critical failure modes and to evaluate design options failure rate or reliability values which could be considered as realistic worst cases should be used.

Whilst these techniques can be used in isolation for specific assessments the real benefits come from their use as part of an integrated ARM & S plan. This allows ARM & S targets to be specified at the concept stage of a project then allocated during design to each part of the system. This information can be used with the appropriate reliability techniques to highlight which parts of the system design require attention to ensure the targets are achieved. The benefits arise from greater transparency and providing control of the design process through
Example of a Reliability Block Diagram for a Main Engine.

Figure 4  Example of a Reliability Block Diagram
optimisation of effort. Other benefits in planning maintenance inspection and spares holding also follow.

**Human Reliability Assessment (HRA)**

No discussion of system reliability would be complete without consideration of human reliability. HRA is the process of quantifying, in probabilistic terms, the reliability of human performance. This is achieved through the assignment of Human Error Probabilities (HEP's) normally associated with the failure to carry out a particular task. The process consists of two distinct phases; the first is the qualitative modelling of the scenario and the second is the actual quantification of the HEP's. Whilst much effort is put into the latter the former is as important if not more so. In order to justify the human reliabilities assigned, the analyst must first establish a sound understanding of the tasks involved, the scenario in which they are to be performed and the factors affecting human performance - so called performance shaping factors (PSF).

The qualitative modelling of human reliability covers three aspects - Task Analysis, Human Error Identification and Human Error Representation.

Task analysis is a method for identifying and assessing the tasks which humans must perform when they interact with a system. It defines the physical actions and cognitive processes which must be undertaken to achieve a system goal. In HRA, task analysis identifies PSF's affecting human performance, and thus forms the basis for the analysis of errors which may occur. There are many task analysis techniques available, ranging from simple observational techniques, through logical frameworks for describing and assessing human behaviour, to complex computer simulations of process activities. Reference 4 provides a review of the task analysis method and its many uses at various stages of the system lifecycle.

Human Error Identification is the process of identifying human failures to achieve a particular system goal. Errors may be classified in various ways depending upon their effect on the system and the purposes of the assessment being carried out. For example, errors may be classified as latent or dynamic, omissions or commission, slips or mistakes and each class may be treated differently in the overall context of a safety assessment. A typical approach to human error identification is to utilise a taxonomy of potential errors and for a human factors analyst to identify those which are likely to occur in the particular scenario of interest. It is worth noting that if this process is taken a step further and the underlying causes
of error and the consequences are identified, then appropriate ways of reducing the likelihood or significance of human errors may be derived. Reference 5 provides detailed guidance on various ways of reducing human error.

Human errors which have been identified must be represented within the context of the overall safety assessment. This may be done through fault trees, event trees or specific HRA event trees. Where human errors need to be combined with hardware failures however the overriding requirement is for compatibility between their representation. An important aspect in the representation of human errors is that of dependence between errors. This may be accounted for by the logic of the fault or event trees, by the use of specific dependency models, or by the use of Human Performance Limiting Values to restrict the claims made upon human reliability.

Reference 6 provides a recent review and comparison of eight quantification techniques. This includes a description of each technique, an evaluation of the techniques against specific criteria (for example validity, accuracy) and examples of the application of each technique through case studies. The techniques all quantify human performance through the assignment of HEP's based on data or expert judgement. Data based approaches use either data deemed to be directly relevant to the errors to be quantified or more generic data which are modified according to the PSF's specific to the scenario of interest. These approaches include:

- Technique for Error Rate Prediction - THERP
- Human Error Assessment and Reduction Technique - HEART

Judgemental approaches may be absolute, where analysts assess the probability of error directly, or relative, where analysts compare or rank error probabilities qualitatively and quantification is achieved by calibration against "known" HEP's. Expert judgement approaches include:

- Absolute Probability Judgement, APJ
- Paired Comparisons
- Success Likelihood Index Method, SLIM.

HRA techniques currently available are generally considered acceptable in terms of their ability to quantify the more 'mechanistic' human errors - failure to carry out a specific check or incorrect operation of a particular control device. However they are less acceptable in terms of their ability to quantify more cognitive errors such as fault diagnosis, or to account for management and
organisational impacts on human reliability. Recent developments have sought to address this problem and will continue to do so in the future. In addition work is continuing within the EEC towards the development of an internationally acceptable standard for carrying out Human Reliability Assessments. It is hoped that a draft version will be available later this year.

The output from HRA can provide quantified input to FME(C)A and FTA as part of a total safety programme, and is particularly effective in safety analysis of man machine interfaces (MMI).

Software Reliability

Software is becoming an increasingly important part of integrated machinery systems. Without it much of the integration, sophistication and flexibility could not be achieved. Use of computer control with often complex software has resulted in simpler more reliable hardware. Yet the safety of the system as a whole is not necessarily enhanced.

Software fails in a completely different way to hardware and this makes it difficult to apply the same techniques for assessing its reliability. For instance software does not wear out and failures due to variability cannot occur since each copy of the original is identical. However if an error is present in the original it will also be present in every copy and will be revealed under identical conditions for each copy. If the error is such as to cause system failure and if the failure is safety related it can be very serious.

Software errors are always due to failure in the "design and execution" processes and not due to usage although they can be inserted during modification or correction. If an error is discovered and eliminated, and no other is introduced, the reliability of the software will increase. The reliability of a piece of software will therefore be a function of the effort and effectiveness put into error detection and correction. It cannot be considered to be solely related to time since an error will only be revealed when a particular path through the program is exercised. Errors which remain in a program after checking validation and testing have been completed are very difficult to detect and as a result there continue to be some misgivings about the use of software in safety critical systems.

The presence of errors in software is essentially due to human failings in the design, production and modification processes. As a result most of the effort in software
reliability is currently being applied to developing methodologies, procedures and techniques for minimising the chance of introduction of errors. A well trained, disciplined and experienced team working to an unambiguous specification and using formal procedures for the various stages of the software lifecycle are far more likely to produce reliable software than one without or with only a subset of these features. Yet the reliability prediction methods available at present do not attempt to quantify these issues, largely because of the difficulty of doing so and the confidence levels likely to be achieved.

A wide variety of models exist for the determination of software reliability, though none have yet gained general acceptance. Because of this diversity and the competing claims of the individual methods the adoption of any approach for quantifying the reliability of a piece of software needs to be agreed between supplier and client in contract negotiations. Typically the techniques that are available are statistical models estimating the number of errors remaining or mean time to failure based on variants of execution time and calendar time given that a certain number of errors have been detected and corrected. More sophisticated methods attempt to take account of the fact that different program errors have different probabilities of causing failure.

There are some difficulties with predicting the number of errors present in a piece of code as the reliability may not be affected by some errors whilst the effect of others may be severe. The use of testing, validation and verification methods is likely to reveal most of the coding errors which occur under common running conditions. Errors in specification and design however may be more difficult to detect and are certainly more difficult to account for in the prediction of reliability.

Lloyd’s Register is currently investing large resources in research in the area of achieving and assessing software reliability. Initiatives to address some of the wider issues affecting software reliability, particularly relating to human performance, are currently underway in the UK’s SAFE-IT programme part sponsored by the Department of Trade and Industry. Lloyd’s Register is involved in programmes to quantify the performance of the software production process in conjunction with Nuclear Electric, Lucas Industries, British Aerospace, Scottish Nuclear, NEI, G P Elliott, The Open University and Warwick University.

One of these programmes is looking at each stage in the software development lifecycle to establish what factors cause faults to arise in software. Using this knowledge it
is intended to derive quantification approaches which will lead to a credible method for quantifying the reliability of safety critical software.

Another programme, recognising that human fallibility is at the root of all software errors is aiming to reduce human intervention in the development lifecycle to a minimum and thus create development methodologies that will result in more reliable software. One example is the use of artificial intelligence techniques in the capture of functional requirements.

Conclusions

The use of formal reliability techniques will become more widespread in enabling system safety to be achieved as systems become more complex and novel solutions are adopted. These techniques provide tested, proven and rational methods for achieving and evaluating system performance.

Further pressures for their adoption are likely to come from possible future requirements for formal safety assessment arising from public concerns over marine safety.

Two areas of particular concern in achieving overall system safety are software reliability and human reliability. In most system automation the drive is towards reducing human intervention to a minimum. Where it cannot be eliminated it needs to be better understood hence the study of human factors will become an increasingly important topic in the future.

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Underlying every successful marine maintenance system, the procedures, and training for personnel is one very important factor. That factor is a built in process to protect human lives and avoid environmental catastrophes— in short, a factor of safety for people and the environment. During the past decade, the world has witnessed agonizing tragedies involving massive fatalities and unequaled environmental pollution. For this reason, it is imperative that any marine maintenance system include what is referred to as "process safety management".

Technological infusion in our planned maintenance programs today provides an exciting challenge to effectively identify and apply what is most cost effective within accepted limits of reasonable risk. Specific applications such as artificial intelligence, expert systems, maintenance management, and monitoring programs are growing. We must not lose sight, however, that these are "tools." They can be no better nor anymore effective than the fundamental logic, the engineering that makes up their development.

We within the industry will continue to see growth in the global sense of environmental restrictions. We continue to grow in our knowledge of the impact of hazardous materials and processes on machinery and personnel. It is likewise important that any applied maintenance program have within its logic base—the latest and most effective response to restrictions and engineered prevention of hazards. It is equally important in this rapidly changing environment, that our maintenance program and/or systems be capable of sufficient upgrade as technology and litigation transpire.

The absolute key to assuring maintenance management application with assured safety and environmental responsiveness is to infuse our development logic at every level with the logic of process safety management. This has been profoundly demonstrated by the on board maintenance management inspections and surveys conducted by Lipe Cycle Engineering in a joint effort with the United States Navy. Our inspections focused exclusively on the daily, monthly, and annual planned maintenance procedures required for fixed machinery, calibration laboratories, ships monitoring systems, and also— those functions supported by auxiliary ships. Having concluded our audit of maintenance requirements and their subsequent implementation on board ship, we then looked closely at the personnel and environmental protection procedures maintained by the ship. Our inspections, or more politely assessments, viewed the prevention of personnel hazards and environmental mishaps as a natural process meshed within the total planned maintenance system. In so doing, we assessed system and process safety, personnel training,
safe work practices and procedures, the abatement of hazards, hazardous materials use and disposal, medical surveillance, personal protective equipment, and hazardous waste spill preparedness, plans and response capabilities on land and at sea. Our summary reports on each aspect of planned maintenance procedures, safety, and environmental protection provided documented evidence of improvement and a clear course of action for eliminating maintenance failures, personnel hazards, and environmental crises. The proof of success is always results — the bottom line — the cost. In these instances the results were highlighted repeatedly by other inspections and surveys conducted by the Navy's own appointed team of experts. The ships efforts had rewarded them handsomely; maintenance procedures were on track and working; and, there were no incidences of personnel or environmental mishaps occurring on the worksite. Typical accomplishment no, but achievable by every maritime unit — yes. The key again is the successful infusion of planned maintenance, safety, and preventive measures at every level, in every person, on a day to day basis.

Process safety management is a system for controlling the hazards to personnel and the environment by comprehensive forethought into all possible disaster sequences. In the development of planned maintenance procedures, it is important to ensure that the equipment is properly designed, installed, and operated; written procedures are established to maintain pressure vessels, piping systems, emergency shut-down systems and controls; evaluating processes within the maintenance arena are used to determine the hazards, the need for engineering controls, consequences of failure, and the effects and impact on shipboard personnel and the environment. Written safety information is provided to employees regarding safe work practices, the hazards of the maintenance processes; procedural steps for operation, emergency operations, shut-down and subsequent startup; employees are trained in these procedures and processes, emphasizing specific safety and environmental hazards, safe work practices, and supplemented by periodic refresher training. Lastly, process safety management is a team concept — backed by top management and infused into every employee in the maintenance organization. Compromising the loss of lives and the environment for profit or production is simply unacceptable; management at all levels is responsible not only for a successful marine maintenance system, but also for the elimination of hazards to employees and the environment.

An effective marine maintenance system is measured not only by the condition of the equipment but also by the costs required to maintain that condition. A well designed and integrated planned maintenance system, when compared to a system of merely corrective action, has been proven to increase equipment reliability, extend operating life, reduce the occurrence of in-service breakdowns, enhance personnel and environmental safety, and use scarce maintenance resources more effectively. The degree to which these benefits are realized will depend upon how well the maintenance requirements are defined and on the assigned frequencies for that maintenance.
Whether the maintenance system utilized is an automated monitoring or a manual recordkeeping system, an effective planned maintenance program must contain four essential elements: 1) identification of equipment and level of required maintenance, 2) development of detailed planned maintenance procedures incorporating safe work practices for each type of maintenance, 3) application of the maintenance and safe work practice procedures by trained personnel, and 4) a feedback mechanism to accommodate continuous evaluation, refinement and upgrading of the maintenance program.

The identification of equipment and level of required maintenance and safety is a critical element in developing a planned maintenance system. The selection of equipment should be based on the cost effectiveness to maintain the equipment in a high state of readiness, criticality to the operation, and the probable consequences of an unplanned failure. Personnel safety and environmental controls should also be considered in equipment selection. Examples of such controls include: the elimination of potential ignition sources, guarding of rotating belts and pinch points, exhaust ventilation systems, noise reduction, hazardous waste minimization, and in-place monitoring for dangerous vapors—all serve to minimize the potential for human or environmental tragedies. An accurate analysis of this information provides a clear definition of equipment which must be maintained.

The level of required maintenance focuses on the identification of failure modes and, more importantly, the types of monitoring needed to identify a degraded condition which leads to this failure mode with the consequences of disrupting plant availability, possible personnel injury, and property or environmental damage. Failure modes are best identified by reviewing previous historical records and an evaluation of equipment operating conditions. Analysis of these factors will lead to the type of monitoring required to identify the onset of a particular failure. This information is crucial in the next essential element of the planned maintenance which is procedure development. Many different types of equipment monitoring methods, many of which are nonintrusive, are currently being used successfully in shipboard maintenance. Those methods most prevalent include vibration monitoring, infrared monitoring, oil analysis, electric motor insulation testing and current signature analysis, ultrasonic flow and radiographic testing. Intrusive methods are also being used; however, the state of the art methods discussed here have proven to be cost effective and quite reliable. Therefore, once the failure mode has been identified, its signatures can be matched to the appropriate monitoring method.

Next, the development of detailed planned maintenance procedures is actually a series of stages in which these procedures become a fluid part of the system. At a minimum, the initial procedures should contain the essential elements of maintenance required by the manufacturer as well as sound engineering judgment on equipment maintenance, operation and safety. The maintenance procedures developed to accomplish the planned maintenance tasks should include the following:
resources required to accomplish the task, including skills, test equipment, reference materials, parts and supporting supplies

identification of equipment location, operating conditions, component isolation, equipment line-up

personnel safety precautions and safe work practices including hazard communication, lock-out/tag-out, required personal protective equipment, confined space entry, posting of specific hazards, engineering control devices, and procedures for emergency shutdown

procedures should be technically valid, tailored to the specific component, comply with design specifications, and ensure quality assurance

lastly, the procedures should be safe —— short cuts are not allowed when there is any doubt concerning the safety of personnel or detrimental impact on the environment.

The language used in the maintenance procedures should be free of vague and ambiguous terms, using simple words and phrases that will convey the intended meaning. Consistency in terminology and organization of material is required for clarity. Procedural steps should be short, concise and written according to the skill level required and training provided to accomplish the task.

Limits on inspections and measurements should be specified so that a condition can be clearly judged as either acceptable or not acceptable. This information can be obtained from inspections and tests performed prior to or during disassembly; GO/NO GO acceptance criteria; requirements for cleaning, refurbishing, and replacement of parts; grooming criteria; and, post maintenance requirements which validate the item for reinstallation and service. In addition to time period —— fixed maintenance, routine inspections and tests should identify condition based maintenance requirements. This information must be merged into the system to lengthen or shorten fixed period maintenance. Information gained from maintenance personnel should also be added to this system so that valuable in-sight regarding equipment operation and safety is not lost.

Implementation of maintenance procedures requires corporate policy and unit procedures to be developed, issued, and implemented; however, it is also important to remember that this implementation requires highly trained personnel, skilled in planned maintenance program functions with the ability to execute changes which benefit the system. Providing for maintenance, program effectiveness, and evaluating component material conditions require maintenance to be accomplished in accordance with standardized procedures, safe work practices, data recorded, and results analyzed to make informed judgment on subsequent maintenance strategies. Maintenance procedures should identify the logistics required to support such maintenance and performed with stand-alone, standardized procedures developed to specifications. This blending of the necessary logistics
and standardized procedures will ensure the successful accomplishment of the maintenance plan. Focused training and strict attention are required to ensure data recording requirements of the procedures are met. The maintenance plan identifies the planned work for the life of the component — it is the driving force that identifies the skills required to accomplish the maintenance, promotes advanced training to ensure qualified personnel, and places the logistical elements within the plan to support the work. The execution of the planned maintenance system relies on the complete thoroughness in the development of maintenance procedures.

With the equipment identified, the maintenance procedures developed, and maintenance being performed, "the closing" of the loop is step four — evaluation of the system. Without a feedback mechanism the planned maintenance system, the system itself can neither improve nor adapt to changing conditions and maintain optimal performance standards. The evaluation phase encompasses the elements necessary to measure and validate the effectiveness of the maintenance program, maintenance plan, and the material condition of the equipment. It requires implementing directives and procedures incorporating safe work practices at all levels to ensure critical maintenance data is collected, processed, stored, analyzed, and reported to the appropriate organizations with responsibilities for these functions. Comparison of observed conditions (e.g., during overhaul) with condition assessment parameters (performance monitoring data) must be made to ensure that monitored values are appropriate for determining equipment conditions. These items should be built into the planned maintenance system or, in other words, implemented at the beginning, so that all involved are prepared to accomplish the necessary tasks for proper assessment.

An effective planned maintenance program must enhance equipment reliability, plant availability, while enhancing personnel safety and minimizing environmental impact. Most importantly — it must represent a sound financial investment. Factors to be considered in assessing program effectiveness are essentially maintenance cost benefits and equipment availability. Maintenance costs may encompass a myriad of individual factors, but for implementing revisions to an existing program — cost benefits are more easily identified by comparing costs to future costs. These costs should not additionally include injury to personnel, loss of life, and environmental pollution, damage, and liability. By instituting an effective planned maintenance program incorporating process safety management, cost benefits are ultimately enhanced and risks to personnel, equipment, operations, and the environment are minimized.

In summary, an effective ship maintenance plan provides the means to maintain equipment reliability for the operational life of the component and is based on the gathering of appropriate data which reflects the performance and condition of the component. It requires maintenance procedures and assessments; tracking and analyzing data to determine maintenance strategies; and trained personnel, with the knowledge of safety, the equipment, and maintenance procedures sufficient enough to
initiate appropriate actions. The efforts of a successful ship maintenance plan serve to improve the overall maintenance program and permit planning for repairs and alterations which prevent catastrophic failures, disruption of plant availability, and endangerment of employees or the environment. An effective marine maintenance system incorporating process safety management is the deciding factor for long term reliability upon equipment, people, the environment, and prosperity.
The role of expert systems and neural networks in the marine industry
J.S. Hobday, D. Rhoden, P. Jones

Abstract

This paper discusses the roles played by expert systems and neural networks onboard ship concentrating upon their uses for machinery diagnostics. It describes the type of advanced system which may become available and require evaluation in the foreseeable future.

Work on the 'Knowledge Based Ship' is described and two future sub-systems, the Collision Avoidance Support System and the Emergency and Damage Control Advisor and Trainer, introduced.

The merits and potential of early and accurate fault detection, diagnosis and estimation of fault severity are discussed together with the relative virtues of steady state and transient monitoring. The abilities of neural networks and expert systems applied to diagnostics are compared and their enhanced effectiveness achieved by using the two techniques together is illustrated by the description of a research fault detection and diagnosis system which utilises this concept.
Introduction

In the early 1980's, Lloyd's Register clearly saw the future importance of computer based engine diagnostics as an aid to efficient machinery supervision and control. At the same time, LR's established policy of promoting research into the application of advanced technology, in support of proper standards of quality and safety, enabled the application of its research resources to the technology of fault detection and diagnostics and other uses of expert systems in the marine industry.

Work also began with research into the fundamental structure and components of diagnostic systems, which then progressed into a study of the nature and characteristics of diesel engine expert systems. In order to gain a proper understanding of the design problems involved, LR decided to develop a diesel engine expert diagnostic system. This has been tested successfully on engines of different design. Other work has involved the study of on-board decision support systems to assist shipboard management, particularly in emergency situations.

A significant amount of work has been carried out into the use of "advanced algorithms" such as genetic algorithms and neural networks. Neural networks in particular are most promising diagnostic tools which can facilitate the correlation and analysis of multiple data streams, such as those generated by the sensors fitted to diesel engines. Interest has focussed on their incorporation in expert systems to allow the benefits of both to be used to best advantage.

The monitoring of transient as opposed to steady state machine conditions is also under investigation and is already proving to be a powerful technique. Its ability to amplify symptoms which may be very difficult to detect at steady state not only provides the possibility of detecting faults earlier, but also requires less precise measurements with potential benefits such as reduced sensor accuracy and cost. Success in this work can be expected to show the suitability of computer based diagnostics for wider employment where the operation of machinery or systems is entirely transient.

The Knowledge Based Ship

In these times of reduced manning and the difficulty in obtaining experienced crews, there are very good reasons for having onboard systems which can detect and diagnose problems and support decision making. Such systems can
add an element of the experience and consistency in decision making which may be lacking, thus increasing awareness and reducing the possibility of misjudgement. This improved performance will be reflected in improved reliability and safety.

The EC Esprit Shipboard Installation of Knowledge-Based Systems (KBSSHIP) Project, in which LR was a partner, successfully demonstrated the concept of a shipboard decision support system. KBSSHIP is composed of a System Manager supported by an expert database containing regulations pertinent to the running and operation of the ship (the Statutory Requirements and Classification Expert System, Figure 1). The System Manager supervises the communication and co-operation between four decision support tools designed to carry out voyage planning, fault diagnosis, maintenance scheduling in the form of the Expert Maintenance System (Figure 2) and cargo planning.
KBSSHIP can be viewed as a successful prototype for shipboard decision support expert systems. It is a practical demonstrator of the types of applications and methods which will allow the introduction of appropriate information technology in support of ships' officers and crews in the future. It will enable the shipboard integrated knowledge base to expand to the full extent required. Such expansion might include a Collision Avoidance Support System which would provide guidance for the Watchkeeper to help him avoid dangerous situations and if they arise give advice and alternative courses of action to prevent collision.

Figure 2. Screen from the Expert Maintenance System
The expansion is also expected to include an Emergency and Damage Control Advisor and Trainer which will provide support for those in command when emergencies occur. Reports of ship accidents show that a support system would assist control of an emergency and could reduce the seriousness of the outcome. Experience in the air transport sector reinforces this view. The benefits would include reduced injuries and loss of life, and reduced damage to both the installation and the environment, with consequently reduced monetary cost.

The Emergency Command Aid part of the system will help the person in command by assisting with assessment of the situation and provide advice about immediate necessary responses and recommended additional actions for controlling the emergency. Conversely the Emergency Simulator Trainer will provide a means for practising the management of fire, damage, or other emergencies as they might occur in the user’s environment. It would consist of a simulator designed to represent the individual ship or installation concerned. It would allow ship or control staff to practise the management of emergency situations as if they were in the real control situation.

Foreseeable improvements and refinements in machinery condition and health monitoring techniques will assist the early detection of machinery faults and their prompt diagnosis and severity estimation. This earlier and better knowledge of machinery problems will be used in conjunction with computer based maintenance planning and ships' voyage planning tools to minimise any adverse effects on the ships' operation. The majority of diagnostic systems are built from rule based expert systems, but there are other methods which can be employed. One set of algorithms which are proving to be very successful are Neural Networks.

The majority of current shipboard applications of advanced support systems are based on expert system technology. An expert system is built upon rules; the harder and faster the rules, the better will the system function. Unfortunately expert systems perform less well when dealing with uncertainty or probability. This is because the expert system reasons according to algorithms in its 'inference engine'. It combines facts from its knowledge base according to the 'book of rules' it has been given. Expert systems, therefore, require an 'expert', either in the form of a 'book of rules' or an authority on the subject, to provide the knowledge and the symbolic model of the task.
However, for many tasks rules are difficult to formulate, consequently rationalisation of the problem is far from easy, creating difficulties in constructing a symbolic model.

By comparison, such tasks can be accomplished by neural networks. Neural networks learn by example; trained on data which represent the problem. Neural networks are trained to adjust the connections between the processing elements (or nodes) so as to correlate the input and output patterns. This means that computing using neural nets is non-algorithmic; there is no algorithm describing the trained network. The 'algorithm' of the trained network together with its 'rules' and 'knowledge base' exist within the complex pattern of connection values which the learning process has produced. Furthermore, this information is not located in one particular place; it is spread throughout the network.

This is known as distributed memory and has the advantage of making neural networks fault tolerant. Because the information is spread throughout the network the loss of some connections, or even nodes with associated connections, does not result in the total loss of information. In fact a reduction in performance may not even be detectable, whereas damage to even a very minor part of a conventional expert system will render it useless.

**NEURAL NETWORKS**

The various types of neural network have been described in detail by Lippmann, 1987 and in the NeuralWorks Software documentation. Karna and Breen, 1989 also provide a very good introduction (in the form of a tutorial) into the workings of neural networks, as does Fougleman-Soulie, 1990.

**Description**

Neural networks can be thought of as general purpose pattern classifiers or matchers which are trained on a representative set of patterns or data. They are capable of classifying patterns which are not in the training set, in other words they can generalize or interpolate. They also have the ability to recognize noisy or partly corrupted patterns. They are fault tolerant in that the network will accept a certain amount of 'damage' before any significant reduction in performance can be detected.

Simulated neural networks are software models based on various interpretations of the structure and functioning of the brain. The artificial neuron is called a processing element or node. It has many input paths and com-
bines, usually by summation, the input values it receives. The combined input is then modified by a transfer function to a new value. This new value becomes the output and can be connected to the inputs of other processing elements through 'weights' which correspond to the synaptic strength of biological neural connections. Each weight has a value which is used to modify the data passing through it. As in the biological brain the neural network learns by altering the values of its weights to try and reduce the error between the output the network produces to a particular input pattern and the required output. This is an iterative process, carried out as the patterns to be learned are presented; an algorithm calculates the error and changes the value of the weights accordingly.

Thus a trained neural network contains all its knowledge in the values of the connections between the nodes, i.e. the value of the weights. The network consists of many processing elements joined together. They are usually collected together in groups called layers. A general structure of a net would be a sequence of layers, starting with

Figure 3. An example neural network
an input layer, followed by a number of hidden layers (hidden in that they have no direct connection to the outside world) and concluding with an output layer.

Figure 3 shows an example of a simulated neural network with an input layer consisting of 2 nodes, connections (or weights) to the middle or hidden layer of 4 nodes and connections from the hidden layer to the output layer of 6 nodes. Figure 4 shows the connections to one of the nodes in the hidden layer and Figure 5 shows how this node processes the data coming into it from the input layer. The incoming value from node 1 (y1) is multiplied by the value of the connection from node 1 to node 3 (weight w13). The same procedure is carried out for the value from node 2. The values coming into the node are first of all summed producing a value X3, which is then modified by the node's transfer function, which in this example is a sigmoid. The transfer function alters the value of X3 to Y3 which is the output value from this node to the nodes in the next layer where the process is repeated.
Figure 5. Function of node 3

There are many types of network, each with various attributes and suitable for different applications. They can be distinguished by:

a) the mathematical formula which the processing elements use to combine the input values (the summation function).

b) the mathematical formula which the processing elements use to modify the combined input values. This is the transfer function.

c) the method of training - the way in which the values of the weights (strength of the interconnections) are adjusted as the network learns. This is determined by the learning algorithm. The learning algorithm is the only preprogrammed part of the network. It determines how the values of the connections in the net are altered in response to the training patterns.
d) the way in which the processing elements in the network are connected which may be described as the network architecture.

Neural networks appear to provide a powerful tool which is likely to be incorporated into future diagnostic systems.

Future of Diagnostics

Steady State Diagnostics

The diesel engine expert diagnostic system (DEEDS), developed under an initiative led by LR, is a steady state monitoring system. The engine must be settled at a steady operating condition before fault detection and diagnosis can take place. The DEEDS system has demonstrated that such systems can achieve high success rates of fault diagnosis (85%) (Banisoleiman et. al. 1991). A great deal was learned through this work and it has formed the basis for further research. One interesting development has highlighted the complexity of symptom patterns at different engine operating points and this confirms the view that more complex rules would be required to be able to improve the expert system's diagnostic success rate. An alternative is to train neural networks to be able to diagnose faults from these complex patterns. In this role the networks are used to the best advantage. The neural network does, however, have the disadvantage that it is difficult to extract the reasoning behind its decisions.

Transient Diagnostics

LR's involvement with the DEEDS project has provided expertise in detecting and diagnosing faults for diesel engines based on artificial intelligence techniques. Whilst high rates of diagnostic success were achieved, the DEEDS project highlighted the fact that this relied on the use of expensive, delicate and accurate instrumentation. The instrumentation problem appears, from the ship owners' viewpoint, to be the main obstacle to general use of this technology, however, other approaches to diagnostics appear to offer advantages which could help to alleviate this problem. One such approach is the monitoring of transients - monitoring the machine or system during changes from one operating condition to another.

Work being conducted within LR has shown the value of monitoring the transient response of a machine. The main benefits being:

a) The detection and diagnosis of faults during the transient which could not be seen during steady state running.
b) The accuracy of the instrumentation required is less critical due to the differences between comparable parameters being exaggerated or amplified during the transient.

c) The combination of the reduction in required instrumentation accuracy together with amplification of fault symptoms reduces the cost of detection and diagnosis.

d) The amplification of the fault symptoms increases the possibility of early fault detection and diagnosis.

The majority of work to date has been carried out on gas turbine transient data. The next phase of the research will aim to investigate to what extent the same benefits of transient monitoring apply to diesel engines and devise fault detection and diagnostic techniques which can take advantage of them. Use is currently being made of a research project into diesel engine emissions produced during transients (Bazari, 1992) to test these ideas.

Fault Severity
Once a fault has been detected sensible decisions concerning the operation, maintenance and repair of machinery can only be made if information about fault severity is available. Being able to estimate and monitor the severity of a fault with confidence greatly assists the decision making process whether it is carried out by man alone or by man supported by machine.

One of the main problems with building systems which will estimate fault severity is lack of adequate data. It becomes very time consuming and expensive to conduct seeded fault trials on a test engine or carry out endurance running hoping to encounter faults. During the diesel engine expert system project, LR conducted comprehensive seeded fault trials incorporating, where possible, two fault severities for each fault. Whilst this set of data gives positive information about how symptoms change, a finer graduation of fault severity is required to provide sufficient data to produce a system to estimate fault severity. This can be achieved by the use of computerized engine modelling and simulation.

LR's MERLIN engine simulation software has been used to model engines for which there are both healthy and faulty engine test data. It has then been possible to seed the engine model with faults of gradually varying severity and record /monitor the way in which the engine parameters...
change. To ensure that the symptoms produced by the simulation are realistic they have been compared with the real engine data.

The advantages of using a simulation to provide the data, compared with collecting it from a live engine, are that:

a) it is much more economical in terms of time and resources

b) symptoms of any level of severity can be produced

c) any engine can be modelled.

This last point is very important for both designers and appraisers of diagnostic systems. The engine diagnostic system designer needs to be able to produce a system which will match the engine required to be monitored. In order to do that he must have examples of the symptoms the engine produces for the faults of interest. The engine simulation route, provided it is proven to be faithful to the real engine, is a very economical way to obtain the necessary engine parameter data. It is also very important for the appraisers of diagnostic systems because any system presented for appraisal can be tested against data from the engine for which it was designed relatively easily and economically. The appraisal can cover the full range of faults and engine operating envelope and, of course, fault severities. With this test of the functionality of the system it will be possible to determine not only whether a fault can be detected but also when.

Work has progressed to produce a system which will diagnose the engine fault and estimate its severity using neural network technology. Currently the work has been based upon steady state engine readings and is still being evaluated. It is intended that this would allow condition monitoring technology to move a step closer to the estimation of the remaining engine life before breakdown or unacceptable performance can be expected. This information could then be used to determine the scheduling of maintenance.

Neural Networks and Expert Systems together

One of the important lessons of the work that has been undertaken has been that while expert systems and neural networks working on their own can be extremely effective, if they can be made to work together the combination can be even more powerful. The comparison between expert systems and neural networks has already been covered. With
knowledge of the attributes discussed it is possible to devise systems which take advantage of both technologies to fulfil specific tasks and there are many ways in which this can be done. One which LR has examined combines two neural networks and an expert system arranged to monitor transient data during the start of a gas turbine as described below.

The Gas Turbine Start Fault Detection and Diagnostic Demonstration System

The demonstration system shows neural networks and an expert system working together. It was designed to monitor gas turbine starts, detect and diagnose any faults which occur and give advice and warnings.

A diagram illustrating the workings of the demonstrator is shown in Figure 6 and is described below.

Data Flow in the Fault Diagnostic System

![Diagram of data flow in the fault diagnostic system](image)

Figure 6. Data flow in the fault diagnostic system
The demonstration consists of three examples of intelligent analysis each triggering an associated graphical output event.

1: The fault detector - a neural network trained to produce a single True/False output. Is there a fault or not? The results of this network are displayed as text in an engine status window. These results would also determine the behaviour of the rest of the program.

2: The fault identifier - a more complex network, only trained on fault data, to differentiate between different types of faults. This is used to interrogate a look up table of fault descriptions.

3: The advisor - an expert system built to decide the severity of the fault. If the fault is classified as serious an immediate warning window is popped up, in a prominent position, advising the user that there is a combustion problem and where it is (Figure 7). If the fault is a temporary, non-serious one then at the end of the

![Figure 7. A Serious Fault Detected](image-url)
demonstration (when a real engine would have reached idle) a window pops up giving the diagnosis of the fault identifier and recommending that the user has the engine examined at the earliest convenient opportunity (Figure 8).

![Figure 8. Detection of a temporary Fault](image)

In addition graphical instruments were incorporated. One, a graph of the minimum, average and maximum gas generator outlet temperature for each combustion can over time was included so that the user could keep track of the start and see when the networks were making their decisions. The second instrument, a circular graph of each combustion can temperature divided by a reference (the average can temperature) allows the user to see the state of the engine combustion graphically. This method of displaying data is proving to be illuminating and is a very useful monitoring concept (Hobday, 1988) and the opportunity was taken to implement it in the demonstration to show it working with transient data.

The demonstration is started by selecting a start data file from the menu. This file contains the measured HP
and LP engine spool speeds together with the gas generator outlet temperatures used to monitor combustion. Once selected the data are read sequentially from the file as if they were being taken directly from a data logging system. It is displayed in the circular display and the average, maximum and minimum calculated for use by the fault detection network with HP and LP spool speed and for display in the form of a graph. Figure 9 shows this for a healthy engine start.

![Start Condition Report](image)

**Figure 9. A Healthy Engine Start**

Once the network detects a fault, that information is displayed in the Start Condition Report window on screen and the input information passed to the second network. The second network is used to diagnose the fault during the time it persists. A window displaying the diagnosis is displayed on screen. This takes the form of a bar chart with the length of each bar proportional to the likelihood of a particular fault being present over the duration of the fault. The length of the bar is calculated from the cumulative average of the outputs from the fault detection...
network, giving a fault diagnosis based upon the whole time that the fault persisted.

This demonstration shows that the two technologies can complement one another and carry out a function neither could easily achieve if used alone.

Conclusion

In this paper we have discussed some of the roles which expert systems and neural networks can perform in the marine industry to give support to the decision makers and thus improve safety, efficiency and availability. Work on the 'Knowledge Based Ship' has been described including two future sub-systems, the Collision Avoidance Support System and the Emergency and Damage Control Advisor and Trainer.

The merits and potential of early and accurate fault detection, diagnosis and fault severity estimation have been expounded together with the virtues of steady state and transient monitoring.

A comparison has been drawn between neural networks and expert systems and the advantage of using the two technologies together to enhance their effectiveness has been explained. A system, constructed as part of a research project, which demonstrates this in a fault detection and diagnosis system has been described.

The knowledge gained in the course of this work will enable the benefits of expert system and neural network technology to be taken properly into account in future ship systems. It will help ensure the safe and correct implementation of this technology with the accompanying benefits of improved quality and safety of operation of the ship and its machinery.

The continuing research programme which is exploring advanced techniques will ensure this knowledge remains at the forefront of technology.

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Expert systems for machinery surveillance

J. Klein Woud

Present-day machinery monitoring systems present on vdu’s the operational mode of the machinery, the values of system variables and generate alarms. In most cases they do not contribute to evaluation of system health or diagnosis of faults. More intelligent monitoring systems should be able to assess system health, predict developing failures, diagnose the failure causes and to give recommendations for operation and maintenance. These expert systems can be based on heuristic knowledge or on deep process knowledge. Model based systems, relying on physical process knowledge, have good possibilities to improve the condition monitoring function. Some aspects of model based systems are reviewed.

Introduction.

Ship machinery installations have a high degree of integration. Electric power and heating are frequently supplied by the propulsion system. This integration is justified by economic reasons: either capital, fuel or maintenance costs or a combination of those are reduced considerably. The plants are provided with a high degree of automation and show, due to technical progress, few failures. On the other hand the integration leads to rather complex plants, where interpretation of condition and diagnosis of malfunctions becomes more difficult.

Furthermore the complement on board ships is changing. The nautical officer controls the ship including the machinery plant. The engineering officer becomes a maintenance manager and hardly has operational duties. Moreover the education of officers has changed: no longer nautical and engineering officers are trained, but "multi-purpose" maritime officers.

All these changes may lead to less experience of the operating officers with interpretation of machinery condition and diagnosis of possible failures. These developments lead to higher safety risks. In order to reduce these risks, more intelligent machinery monitoring systems are required. These may also contribute to a further reduction in ship’s personnel.

Present-day computer based monitoring systems present on vdu’s the operational mode of the machinery, system variables and generate alarms. However these systems do not contribute to the evaluation of system health or the diagnosis of faults. Intelligent monitoring systems have a number of additional advisory tasks:

- Continuous evaluation of machinery health and indication of developing trends.
- Diagnosis of failure causes.
- Prediction of the time when a developing failure becomes critical and indication of maintenance tasks.
- Indication of how to operate the machinery with a (developing) failure.
- Explanation of the reasoning behind the diagnosis and advises.

Such "expert" systems can be based on heuristic and/or on knowledge of the process physics. Heuristic knowledge is the result of experience of designers, operators and other experts with the machinery plant and its behaviour after failures have become manifest. In such a case the relation between symptoms and causes is known, but frequently the physical process cannot be explained.

In case of sufficient deep knowledge of the physical process being available, one will be able to make mathematical models of the machinery. These models can be used to predict the operational behaviour of both the healthy and the malfunctioning system. For machinery expert systems one can use both heuristic and process knowledge. For complex machinery the real process knowledge may be too limited to rely on. Heuristic knowledge, however, is difficult to acquire and experts frequently have contradictory opinions. Implementation of heuristic rules in diagnostic systems can be time-consuming. On the other hand deep process knowledge enables better prediction of machinery behaviour and diagnosis of faults. This paper discusses some aspects of intelligent
monitoring systems relying, as much as possible, on knowledge of the process physics.

Projects on machinery expert systems.

Both types of systems, heuristic and model based, are the subject of research all over the world. Research, aiming at marine applications, is reported for instance by: [Ahlqvist, 1991], [Dabbar e.a., 1989], [Elliot e.a., 1990], [Katsoulakos e.a., 1988, 1989], [Richards, 1988], [Roselund e.a., 1988], [Ruxton e.a., 1988], [Siebert e.a., 1989], [Shamsolmaali e.a., 1991].

Delft University is involved in the ICMOS project. ICMOS involves research in Intelligent Control and Monitoring of marine machinery Systems. The project is sponsored by the Dutch Foundation for Maritime Research, the Shipowners’ Associations and Royal Netherlands Navy. Other partners in the project are NEVESBU/LOGOS, Stork Wärtsilä Diesel and Croon.

DUT is cooperating in the following sub-projects:
- with Stork Wärtsilä Diesel an intelligent diesel engine monitoring system is being developed, which will be able to assess the engine health, to diagnose the causes of faults and to indicate the remaining life before limits will be exceeded. The project addresses primarily the thermodynamic process. A basic feature of this system is that the number of sensors should not be increased compared to a standard surveillance system. [Jaspers e.a., 1990]
- with van Buuren-van Swaay a study is being conducted to the feasibility of an expert monitoring system for compressor cooling/refrigeration plants.
- a fundamental research project into diagnostic methods for machinery and sensor failures. In this project the cooling system of a diesel engine is used as an example.

Model based systems.

For determination of machinery condition it is necessary to know which values process variables should have in healthy state. For an alarm system these references consist of limit values, which should not be exceeded.

For a more intelligent system, one wants to have early information about the machinery condition. This requires a reference model of the machinery which can predict variable or parameter values, with a high accuracy, in all operational conditions. By comparing actual values of variables of the running machinery with those of the reference model, it is possible to conclude whether the system is healthy or whether there is some form of malfunctioning.

After having concluded that there is a malfunction, one wants to diagnose the cause. Therefore, diagnostic techniques are needed which are based on the relation between symptoms (deviations of actual and reference values) and possible causes. The diagnostic model can consist of a set of rules, based on heuristic and/or deep process knowledge, but can also be a mathematical procedure, which translates symptoms into possible causes.

Sensors are an essential part of the monitoring system. They produce measurement values, which can deviate from the real values due to sensor drift and failures. Sensors are recognized sources of trouble in monitoring systems. In order to realize a reliable expert monitoring system it is therefore necessary to include sensor monitoring.

Deviations from healthy machinery operation should be detected in an early stage. It is next of much interest to predict when the machinery condition will have deteriorated so much, that correction of the looming fault, i.e. maintenance, is required. Therefore trend analysis and prediction are essential, as well as advises how to operate the machinery with the lowest risk for critical situations.

Reference models.

The simplest form of reference model is a set of formulae, which have been obtained by curve fitting using test bed or sea trial measurements. During
development of the reference model the machinery system must be healthy and running in an operational condition close to the actual, preferably with the same sensors as used for the monitoring system. The result is a reference model with a good accuracy, but, because no process knowledge is included, only suitable for the operational conditions at which the measurements have been taken. Such a reference model, as for example a diesel engine running on propeller law, generates the relevant variables (temperatures, pressures, speeds, flows) as a function of a few operational parameters (e.g. engine speed). The model will show deviations in circumstances other than during trials, for instance due to increased propeller load or another ambient air temperature.

Good process knowledge enables reference models, based on the physics of the process. In general this makes the model more suitable for variations in ambient and loading condition. When, however, a model is based on theoretical data only, the accuracy might be insufficient. A sound way of developing a reference model therefore is to use physical relations which should be matched to the actual machinery on basis of measurements.

An empirical reference generator can be made rather easily for the complete machinery system, as for example the model of a diesel engine as discussed above. A physical model of the complete system will be more difficult to develop, because not all necessary knowledge might be available or development and matching might take much time. Both for condition determination and diagnosis tasks, it is however not mandatory to have a reference model of the complete system. Smaller models of system components could be sufficient and be more powerful.

In a component reference model the healthy output variables (measurement signals) are, based on physical knowledge, given as a function of input variables, which define the operational condition, see figure 1. The reference model could also involve the determination of component parameters, such as a heat transfer coefficient, see figure 2.

![figure 1: A component reference model to determine its condition: healthy or malfunctioning.
The input variables should determine the operational condition completely.
The output variables are direct measurements such as temperatures and pressures.](image)

As an example the reference model of a diesel engine air cooler is described and compared with the model of a complete engine. In the complete engine model the temperature after and pressure drop over the cooler might be given as a function of engine speed only. A more detailed description of the engine model, with more input variables would be too complicated. With these two variables the cooler operational condition is not fully determined however. The cooler function is depending on inlet air and water temperatures, air pressure and mass flows as inputs. As output variables the air and water temperatures after the cooler and pressure drops can be regarded.
figure 2: A component reference model to determine actual process parameters, such as a heat transfer coefficient and a pressure loss coefficient.

With the engine reference model one may conclude there is too high a temperature after the cooler, which, for example, not only could be the result of:
- cooler fouling
but also of:
- too small a cooling water mass flow due to a pump problem
- too high a water inlet temperature due to a control valve failure
- too high an air inlet temperature due to a compressor malfunctioning
This means that, with such an overall model, a deviation from the healthy state does not give a direct clue to the origin of the problem.

With a cooler reference model, involving a set of input variables, which fully defines its operational condition, the influence of other components is eliminated. Now a too high air temperature after the cooler can be the result of a cooler problem only.
diagnostic tasks. The component is separated from the influences of other system parts. The model leads to conclusions about the condition of that component only. In addition it is more likely that sufficient process knowledge for a component reference model is available than for a complete system model.

Figure 3 gives an indication of how the reference model for a diesel engine air cooler could be set up. This model produces the temperatures after and pressure drops over the cooler and can be used to diagnose fouling problems. Figure 4 shows a reference model which produces parameters like an additional thermal fouling resistance and a pressure loss coefficient, which can be used for the same problems.

**Figure 4:** Use of a reference model for diagnosis of air cooler faults.

In this model condition parameters are determined which indicate:
- \( R_{\text{therm}} \) = additional thermal resistance compared to healthy cooler
- \( R_{\text{fou}} \) = increase of resistance factor both on air and water side

These conditioning parameters are to a large extent independent of the cooler loading condition. This facilitates the evaluation of trends during different operational conditions.

Diagnostic techniques.

After having concluded that there may be some form of malfunctioning, it is necessary to determine the cause. Therefore one needs to know the effect of failures on system variables and to have diagnosis techniques at one's disposal.

Both cases, the reference model involving the complete machinery system and involving only a component, will be discussed. For a complete system the number of possible failures can be large.

**failures and failure-symptom identification.**

The possible failures in the system have to be determined, for which two methods can be applied:
- interviews with experts, like designers, operators and maintainers.
- analytic methods, where failure possibilities are systematically reviewed, for instance by a failure mode and effect analysis.
It is important to have a complete list of failures, otherwise one can expect difficulties during the diagnosis process when an unforeseen fault occurs. In such a case the diagnosis probably will lead to one or a combination of wrong conclusions. In the DUT projects both methods: interviews and analytic techniques are being applied. In this way a check becomes available both on the outcome of expert interviews as on the analytical study. Less probable faults should be considered too. The operator needs the expert system especially when an improbable fault happens.

The symptoms, deviations of actual measured variables compared to the reference values, caused by a failure, need to be known. These relations between failures and symptoms, in the form of a failure-symptom matrix, can be given in a qualitative or quantitative way. Qualitative information is given as a pattern per fault: some variables will show an increase, some will decrease and others may be unaffected compared with the reference value; certain variables have no relation with the fault. A typical example of these patterns is given the matrix of table I. This type of knowledge can be obtained by interviewing experts. It is however difficult to get good information how big a deviation will be. Usually the experts know how the system reacts to a failure but, especially for rare failures, they do not know whether a deviation will be 1 %, which probably is within the tolerance range of the sensor, or 3 or 5 %.

A better method to obtain quantitative information is to use measured data of the malfunctioning system. This is used for instance by [Shamsolmaali e.a., 1991]. Unless measured information is available from actual operation or trials, not specifically done for this purpose, tests are very expensive. Therefore use of simulation can be an attractive alternative. This requires good process knowledge and an accurate and reliable simulation model of the system, in which one can introduce the failures. For the diesel engine expert system, being developed by Stork Wärtsilä Diesel and DUT, this method has been applied [Fase, 1992]. Here use has been made of a diesel process cycle programme, developed by SWD for design evaluations. Adaptations to the model enabled simulating faulty conditions. Much attention has been paid to match the programme to the actual engine, so that the reliability of the symptoms will be high. The matching was done for normal operation, where a lot of engine data are available, but also for a number of off-design conditions. The results of the matching simulations warranted confidence in the other results. Also special attention had to be paid to how faults should be introduced in the simulation. As an example compressor fouling cannot be introduced directly in the simulation, but reduction of compressor efficiency and pressure ratio is possible. The relation between fouling and efficiency and pressure ratio is, however, only marginally known. Therefore, it has been decided to investigate instead of compressor fouling two independent other faults: reduced efficiency and reduced pressure ratio. This means, that the diagnosis cannot directly conclude there is a fouling problem, but some combination of efficiency and pressure ratio reduction. This dual diagnosis leads of course to the probable conclusion of fouling.

Qualitative failure diagnosis.

With the failure-symptom matrix known, it is possible to diagnose the probable failures, after establishment of the deviations between actual and healthy condition. If the matrix is available in a qualitative form, the diagnosis task can be performed in a number of ways, for example by:

-a reasoning procedure, with rules, as is the case with many expert systems.
In a rule-based system it is fairly easy to recognize a fault when the symptom pattern is equal to that of the matrix. However, it is more difficult to diagnose a fault by reasoning when the symptoms are not fully, but only partly, identical to those of the matrix. Reliable diagnosis, also with partial symptom identity, is important, because such situations may be expected to happen frequently. This can occur due to stochastic influences, sensor inaccuracies, combinations of failures and when a failure is in an early stage. A reasoning procedure, for a large machinery system, capable of coping with these situations, proved to be complicated due to the combinatorial explosion of rules. It also appeared to be difficult to develop such a complex rule base.

Another pattern recognition technique [Herwerden, 1992], which can be implemented in an easier way and nevertheless leads to reliable conclusions, is the following:

For each known fault in the matrix a probability score is evaluated, which is an indication how much the matrix symptom pattern is in conformity with the actual pattern. This is achieved by giving each pattern element a score. The maximum score of all symptoms of a failure equals 100. The score for each element is determined on the basis of knowledge about the particular failure symptoms. A variable which shows a very distinct reaction to a fault will get a higher score than a variable which shows only a limited reaction to that failure. As an example, failure A of table I could have the following scores:

<table>
<thead>
<tr>
<th>variable</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>...</th>
<th>p</th>
<th>q</th>
<th>...</th>
<th>x</th>
<th>y</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>symptom</td>
<td>&gt;</td>
<td>≤</td>
<td>&gt;</td>
<td>≥</td>
<td>&gt;</td>
<td>≤</td>
<td>?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>score</td>
<td>30</td>
<td>5</td>
<td>10/5</td>
<td>10/5</td>
<td>5</td>
<td>30</td>
<td>10/5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Depending on the total score, a classification of the probability of the faults can be made, e.g. as follows:

- score ≥ 90 : probable fault
- score ≥ 65 & < 90 : possible fault
- score < 65 : unlikely fault

During a limited number of tests this method of pattern recognition appeared to be effective. In the near future more extensive testing of the method will be performed on the basis of computer simulations. The method can be extended to diagnose multiple faults. A comparable method is described by [Shamsolmaali e.a., 1991].

Quantitative failure diagnosis - vector analysis.

When the failure-symptom matrix is known in a quantitative form, it becomes possible not only to diagnose failure occurrence, but also to calculate the severity of that fault. The matrix contains influence numbers \( m \), which show for a "standard" fault (e.g. a fault with the maximum allowable severity): the change of a variable compared with the healthy reference condition.

As the number of measured variables is \( p \) and the number of defined faults is \( q \), the matrix can be regarded as a \( p \)-dimensional space in which the maximum of each fault is represented by a vector, whose projections are equal to the influence numbers (figure 5).

If a linear behaviour of the faults is assumed, the symptom can, depending on the occurred faults, be expressed as follows:

\[
s_i = m_{i1}f_1 + ... + m_{ij}f_j + ... + m_{iq}f_q
\]

where \( s_i \) = symptom: deviation of variable \( i \) compared with reference condition

\( m_{ij} \) = influence number for variable \( i \) due to failure \( j \)

\( f_j \) = severity of failure \( j \)

The number of these equations will be equal to the number of sensors, which is the number of measured variables: \( p \). For a running machinery system the \( p \) variables can be measured, and using a reference generator the symptoms \( s \) can be determined which leads to a set of \( p \) linear equations with \( q \) unknown failure severities \( f \).
The principle of diagnosis according to vector analysis.
This example shows the situation with 3 measured variables (sensors) $M_1$, $M_2$, and $M_3$.
There are two known faults in this system, indicated with $F_1$ and $F_2$.
Fault $F_1$ has as influence numbers, the projection on the main axes' $M_1$, $M_2$, and $M_3$: $m_{11}$, $m_{21}$, and $m_{31}$. ($m_{11}$ is the symptom of variable 2 due to standard fault $F_1$).
$S$ is the measured symptom vector in actual running condition. Without sensor and model inaccuracies $S$ should lie in the plane $OF_1F_2$.
In reality $S$ is outside that plane. The projection of $S$ on $OF_1F_2$ is $S'$. The deviation vector $d$ between $S$ and $S'$ complies with the least square criterion. $f_1$ and $f_2$ are the projections of $S'$ on $F_1$ and $F_2$.
They represent the diagnosed severities of faults $F_1$ and $F_2$.

This set of equations has, in matrix notation, the following form:
$$ S = M \cdot F $$
where
- $S(p)$ = symptom vector
- $M(p,q)$ = matrix of influence numbers
- $F(q)$ = failure severity vector.

The failure severity $f$ will have the value 0 in healthy condition and 1 for a failure with severity according to the "standard" failure.
If the number of variables $p$ is larger than or equal to the number of failures $q$ and if the matrix is regular, it is possible to solve this set of equations leading to the desired diagnosis: the severity of the faults. With $p > q$ there are more equations than unknowns and there is also more than one solution. A single solution, according to the least square criterion, can be obtained by pre-multiplying the set of equations with the transpose of $M$:
$$ M^T \cdot S = M^T \cdot M \cdot F $$
This is a set with $q$ equations and $q$ unknowns, which can be solved with standard mathematical routines. The resulting diagnosis may show inaccuracies due to faulty influence numbers of the failure-symptom matrix, as well as sensor and reference model faults.
Investigations showed, that these diagnosis faults can be minimized by more
advanced mathematical methods, where pre-multiplication of the equations with the transpose of M is not necessary [Nielen, 1991]. This method, within ICMOS called vector analysis, uses singular value decomposition and scaling of rows and columns of the matrix.

Even with advanced solving methods it remains essential, that the faults of matrix and sensors is kept low. With a reasonably good conditioned matrix it is possible to diagnose the faults with an accuracy of 30 %, when the faults of the matrix and sensors are in the order of 10 % and 4 %. An accuracy of the failure severity prediction of 30 % is felt to be acceptable, especially when trend analysis techniques are added, to get more feeling for development of failures.

The singular value decomposition technique, used for solving the equations, also provides a lot of information about the condition of the failure-symptom matrix and indications of how to improve it. When two (or more) failures show a strong dependency, which means they give almost the same symptoms, it is hardly possible to discriminate between these failures during diagnosis. With the developed technique it is possible to predict in advance whether the defined failures can be discriminated and, if not, which failures are strongly interdependent. In such a case one may be forced to combine these failures to a single failure, which can be diagnosed much better, or to look for an additional measurement resulting in better information. The technique also gives information whether all sensors are really necessary for reliable diagnosis, or whether diagnosis is still possible with failure of a certain sensor.

component monitoring.

With a component reference model, diagnosis of faults is relatively easy. For the cooler model of figure 3, it is obvious that an increase of the temperature at the cooler outlet indicates a fouling problem on the air or on the water side, whereas an increase of pressure drop is a result of reduced flow area. The model of figure 4 also easily leads to conclusions: a positive additional thermal resistance means cooler fouling. Within ICMOS this type of reference model and diagnosis is called component monitoring [Bergman, 1992]. It is felt that this technique can be very powerful. Its limitation lies in the fact that all actual input and output variables for the component reference model need to be known. For the cooler example this means that one needs four temperatures (air and water, in and out) two mass flows and one pressure. Especially measurement of the mass flows could be complicated, costly and also not very accurate. To reduce this drawback, use of estimators instead of sensors can be considered. As an example it is possible to estimate the air mass flow of a four-stroke diesel engine rather accurately with a model which includes engine speed, receiver air pressure, swept volume and a correction for scavenging.

Influence of sensors.

Sensors play a vital role in any machinery monitoring system: wrong sensor information easily leads to wrong conclusions. It is also well known that a 100 % reliable sensor does not exist. Based on these considerations the number of sensors should be kept low and reliable types should be selected. In order to prevent an incorrect condition assessment and a wrong diagnosis it is essential that also sensor reliability will be checked in an expert monitoring system.

Sensor diagnosis can be based on individual sensor behaviour. This means that some trivial checks can and should be made:

- a check for short circuit and wire failure
- is the raw sensor signal within the measuring range?
- is the rate of change of a sensor signal compared to the previous sample physically possible?

Next to individual sensor surveillance it is possible to use redundancy. Installation of more than one sensor for an essential variable is an obvious solution. However in the maritime industry this option is not much appreciated, because it adds complexity, costs and additional possibilities for failures. A more attractive type of redundancy is the use of redundant information of different sensors. Checks, which can be made in this sense, are:

- is the sensor signal, before starting a "cold" system in accordance with ambient conditions?
is the measurement physically possible in relation to other sensors? Observer and filter techniques can play a role in this type of sensor diagnosis.

In ICMOS sensor surveillance will be adopted as far as possible. If the monitoring system detects a possible sensor malfunction, the operator will be informed about this conclusion and the reason for the suspicion. The operator has to decide whether the sensor information still can be used, or that the system should discard the concerning sensor. In the last case it may be that a part of the diagnosis is not longer possible. With vector analysis a missing sensor means that the number of equations has been reduced. This can imply that the same failures can be diagnosed as before, but probably with lower accuracy. The other outcome could be that certain failures cannot be discriminated anymore and have to be combined. For proper reaction of the system on sensor failures it is important, that one investigates what a missing sensor means on the diagnostic capabilities and the relevant modifications to the diagnostic process are included.

Trend analysis and prediction.

Surveillance of a machinery system should be possible during all operational conditions. It is also desirable that the diagnosis can be performed in each situation. Further one wants to have a feeling for the trend of system variables and malfunctions. To enable the interpretation of trends, it is important that the information is not depending on the operational condition. An example may illustrate this; The pressure drop over an air filter is measured, because it can be used as an indication of fouling. When the filter is always in the same operational condition: filtering a constant air mass flow with a constant temperature and pressure, trend analysis will pose no problems. In that case pressure drop indeed will be a good indication of filter cleanliness and a trend plot will have a clear meaning. The situation changes in case the filter operates with a varying air mass flow. Now the pressure drop will not only be a function of filter cleanliness but also of mass flow; a trend plot will not show a clear picture.

To make trend analysis meaningful it is thus desirable to determine system variables, which are load independent. For the filter this could be done for instance by division of the actual pressure drop by the reference pressure drop. The reference value being the pressure drop, with clean filter, as a function of the operational condition (e.g. mass flow). This relative pressure drop would be a much better indicator for filter fouling than the actual pressure drop. Another solution might be to calculate a resistance factor from the measured pressure drop and the air mass flow. This parameter also will be a good indicator of filter condition.

For a cooler load independency is a bit more difficult to achieve. If the relative outlet temperature of the cooler (actual outlet temperature divided by the reference outlet temperature) is used as an indication of cooler condition, the following problem would arise. The effect of cooler fouling at high thermal load will be much larger than during low loads. This means that a fouled cooler at high load will show a higher relative temperature than at low load, which results in an unclear trend plot. A better solution might be, to use the additional thermal resistance due to fouling, as a condition indicator, instead of outlet temperature. The calculation of such a condition parameter in different loading conditions requires of course a thorough physical model. The relevant model is shown in figure 4.

In ICMOS much attention is paid to get load independent variables or condition parameters. In general it requires good process knowledge and awareness how failures affect system variables to achieve this goal.

During condition monitoring it is important that the conclusion of a machinery health deterioration has a high reliability. One is not interested in unjustified indications of malfunctioning. On the other hand it is essential that developing faults are detected in an early stage. These requirements are contradictory and are much influenced by sensor and model accuracies. Because sensor accuracies frequently are of the same order of magnitude as the deviations of process variables between healthy and malfunctioning state, this aspect deserves attention.

In ICMOS the problem has been tackled by using not only the real time symptoms for condition assessment, but also by using the available trend information.
If the real time symptoms are used large tolerance ranges have to be applied to prevent too many unjustified conclusions of health deterioration. This means that such a conclusion may be drawn in a far developed stage of malfunctioning for the first time. When, however, also the trend information is being used it is possible to reduce the tolerance range considerably, because a major part of the sensor inaccuracies have a stochastic behaviour. This means that much earlier detection of malfunctioning becomes possible, without an increase of unjustified conclusions. The resulting system uses real time and geometric weighted history data. It ensures a low probability of unjustified conclusions, a reasonable quick reaction time for slowly developing faults and an almost instantaneous reaction for fast developing failures. Investigations, for the diesel engine project, indicated that the tolerance ranges could be set such, that the probability for a false indication of deteriorated condition is in the order of 0.3 %.

For a quantitative diagnosis process, such as vector analysis, it is important to use, as inputs, data which are as little as possible disturbed by inaccuracies, because this may lead to diagnostic misinterpretation. Thus it may be advantageous not to use the last measured data, but to use "corrected" data, based on trend information. The implementation of trend data in the diagnosis input can be done in several ways. One tested method is described. The trend prediction has been made with a linear and exponential function. The function is determined with a least square method, based on the recorded history and last measured data. This technique has been applied on a diesel engine on a test bed, which experienced, during the period of testing, a.o. fouling problems in the turbocharger. The diagnosis, according vector analysis, has been performed, during the test period, several times. The diagnosis based on the measured data came to correct results, but showed in the time for some faults a variation, due to inaccuracies in the input data, of approximately 30 %. With the corrected data, according to a linear trend, the variation was (somewhat) reduced. With a correction, according to an exponential trend, the improvement was less. From this experience one may not conclude that a linear trend will always give better results than an exponential. It is assumed, that this is much depending on how the particular deterioration progresses in time.

The trend prediction as described can be used also to give an indication of future behaviour of the machinery system: when a limiting value might be exceeded and thus when maintenance has to be performed.

Conclusions.

Intelligent monitoring systems for ship's machinery installations can contribute to safety and economy. As, in the near future, ship operators will get a general nautical and not anymore a specific engineering education and also will have less experience with machinery surveillance, expert systems may improve safety of machinery plants. The economical advantage of intelligent systems is achieved through possible crew reductions and improvement of the maintenance function.

Many machinery expert systems are still based on heuristic knowledge. Deep process knowledge, often in combination with experience, will improve the capabilities of the intelligent monitoring system. A lot of the expert systems now in operational use are regarded by the present engineers as "nice to have toys". They contribute to health analysis and fault diagnosis but are not yet indispensable. In the future more advanced systems may make themselves indispensable, especially due to crew developments.

Cost considerations, most probably, will prevent that very extensive instrumentation will be installed on line, with the only purpose of the intelligent monitoring system. The optimal machinery surveillance therefore might consist of an on line system, with a relatively limited set of sensors plus an extensive off line diagnosis system, with advanced measuring techniques. The off line system can be used for a complete fleet instead of one ship and needs only to be used after the on line system has indicated that there is a malfunction, with the probable cause or location of the fault.
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Abstract
Over the last decade the Maritime Industry has gained vast experience in the automation of advanced ships and offshore work platforms, such as dredgers, naval vessels, and crane and pipelay barges.

Up until five years ago dedicated computer hardware is typically employed, but was often placed next to manual controls as an extension. The industrial hardware now available is becoming more and more advanced and is allowing the creation of reliable "Integrated Control and Automation Systems", which will, as costs decline with time, also be applicable on less advanced ships.

This paper describes the development of ships' control systems, from manually operated, to integrated automation, and the influence of this kind of automation on the reliability of operations and safety on board.

Introduction
Integrated Control and Automation of ships is a logical step beyond the more traditional control operations on board. This mirrors a trend set in the industrial world of automation. In industry it has been necessary to remain competitive and meet the increasingly stringent legal standards on quality (liability) and safety (including environmental aspects). This also applies to shipping. Much can thus be learned and adopted from these industrial trends. The experiences described below took place at Van Rietshoten en Houwens (Technology) B.V., a company active in the fields of industrial and maritime automation.
Development of automation/computerisation capabilities

Until 1970 automatic control was primarily accomplished using techniques current at the time, such as relay control and regulation with the help of analogue (electronic) amplifiers. As from 1970 the then recently available mini-computers (such as type PDP-8) were used for extremely difficult and complex automation problems. At the time these were very large and expensive computers. One application for which they were used in the '70s was the commonly seen Dynamically Positioned Drill Ships, which could remain in precise position without mooring while drilling for oil or gas. Because of the precision called for in holding the correct drill location, automatic control proved indispensable. This job was done by the then mini-computers, sometimes still provided with analogue back-up systems, built up from less sophisticated analogue controllers. [1].

Around 1975 the first micro-processors with a calculation capacity comparable to the mini-computers arrived. These micro-processors were much smaller and also much less expensive, which meant they could be used for simple measurement and control equipment or for more complex applications for which less money was available [2]. Using these micro-processors many automatic control systems were developed that were placed in parallel with the manual controls [3] [4].

Figure 1: Task of different kinds of hardware.
In 1980 came the PLCs (Programmable Logic Controllers) to replace relay controls. As from 1985 they could also execute analogue control functions. This made it possible to reduce a substantial part of the applications for micro-processors. In other words, the PLCs took over these applications. As from 1985 the PC (personal computer) arrived on the scene, even on board ships. They were often used to collect information (data logging), to aid in making strategic decisions, and to present information. These PCs took over some of the applications previously filled by micro and mini computers. The development described about is shown diagrammatically in figure 1.

The need for automation and motivational elements.

Automation is no goal in itself, but has to serve a clear function on board. The capabilities of automation depend on application needs. Automation is necessary for:

- required precision
  - position control
  - process efficiency
- complex coordinated tasks
- reduction of manpower
- trend analysis
- integration with
- safety
- combinations of the above

An important proportion of these automation tasks are automatically stimulated by the economic benefits inherent to them. However, two aspects are not stimulated by economic advantage. They are:

- automation for purposes of safety and security,
- integration of the various control, monitoring and navigation systems.

Both elements offer less obvious economic advantages; an advantage over the long term (safety) and an advantage for unambiguous and therefore safer operation (integration).
These elements should be stimulated by international regulations (incl. IHO and IMO). And the international regulations should be adapted such that any legal obstacles hinder new applications less than in the past. Consider the introduction of the Electronic Chart Display and Information System (ECDIS), for example.

Automation Concepts

The above shows that in many areas automation (i.e. the application of computer systems) is or will be applicable on board ships.

Table 1: Importance of automation

<table>
<thead>
<tr>
<th>.</th>
<th>transport ships</th>
<th>ferries ships</th>
<th>naval ships</th>
<th>dredgers</th>
<th>pontoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine room</td>
<td>++++</td>
<td>++++</td>
<td>++++</td>
<td>++++</td>
<td>++++</td>
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<tr>
<td>Propulsion</td>
<td>++++</td>
<td>++++</td>
<td>++++</td>
<td>++++</td>
<td>+</td>
</tr>
<tr>
<td>Course control</td>
<td>++++</td>
<td>++++</td>
<td>++++</td>
<td>++++</td>
<td>++</td>
</tr>
<tr>
<td>Roll/list control</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>++++</td>
<td>++++</td>
</tr>
<tr>
<td>Position control</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>++++</td>
<td>++++</td>
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<tr>
<td>Navigation</td>
<td>++++</td>
<td>++++</td>
<td>++++</td>
<td>++++</td>
<td>++</td>
</tr>
<tr>
<td>Loading</td>
<td>++++</td>
<td>+++</td>
<td>+</td>
<td>++++</td>
<td>+++</td>
</tr>
<tr>
<td>Safety/stability</td>
<td>++++</td>
<td>+++</td>
<td>++</td>
<td>++++</td>
<td>++</td>
</tr>
<tr>
<td>Damage control</td>
<td>+</td>
<td>+++</td>
<td>++++</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>Process control</td>
<td>+</td>
<td>++</td>
<td>++++</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>Communication</td>
<td>+</td>
<td>++</td>
<td>++++</td>
<td>++</td>
<td>+</td>
</tr>
</tbody>
</table>

This table shows that on all vessels the engine facilities (engine room), propulsion, course setting and navigation are all equally important. This is not surprising as they are the basic tasks of the ship. For these functions there are many standard solutions also readily available:

- engine room automation
- pitch control/load sharing
- auto pilots
- radar, GPS, ARPA, (ECDIS)

A disadvantage of these standard solutions shown above is that each element has its own control and presentation system by which control and presentation is carried out in many different ways and at various locations. In addition to this, the volume of information for presentation and operation on the bridge has increased in recent years for two main reasons:
- the volume of information has increased as a result of technical performance
- in endeavouring to limit the size of crews, more information has to be processed for, and decisions taken by each crew member (particularly on the bridge).

In the interests of safety the provision of information and control operations should be more uniform. This can be best accomplished through the integration of presentation and control functions. This integration will also achieve a reduction in the size of the control and presentation system (the so-called 'integrated bridge'). When this integration is not limited to the presentation and controls on the bridge but also automates functions, a completely integrated system is achieved with the following benefits:

- high degree of automation;
- optimal presentation of information (depending on process status);
- high degree of coupling and interlocking of separate automated functions;
- easily connected to other computer systems;
- easily adapted to new (future) circumstances;
- reduction in the number of individual measuring and control devices and in the amount of cabling required, leading to an increase in "Mean Time Between Failures" and a simplification of fault-finding procedures;
- standardisation of components;
- possibilities to achieve a "Decision Support System", by using an "expert system" for example.

In addition to the advantages mentioned the following negative points should be borne in mind:

- the added value per operator drops per control and automation function,
- a higher level of operator training is required.
In the same training time the "Multi-skill Officer" must learn more (concerning deck operations, navigation, engine room, radio etc.) by which this more general knowledge is frustrated by the dullness of work on board
- operation and presentation will be different for each type of vessel by which the "exchangeability" of operators is reduced,
- increased dependence on sensors by which on breakdown difficult manual back up situations are created.

A number of the disadvantages mentioned above can be reduced by training (also with the use of simulators) and by the application of "Decision Support Systems".
Examples of 'Integrated Control and Automation'.

**Warships**

As shown in figure 1, up to five years ago automation was carried out with the aid of mini or micro computers. This was particularly the case for ships for which very complex automation and decision functions are necessary. An example of this is the on board automation of Dutch "M" (multi-purpose) class frigates [6]. In addition to the general advantages of the integrated approach, this application also affords a very high vessel availability. That is why a Damage Control System [9] has been integrated into the total concept by which damage control can be coordinated from various locations (work stations) on board ship (see figure 3). From these different work stations all other control and monitoring functions can also be carried out. Figures 2 provides an example of such a control station.

![Operator work station in the ship's Control Centre](image)

**fig.2.** An operator work station in the ship's Control Centre illustrates integrated capabilities.

It goes without saying that this approach is indispensable for warships. But a similar approach has also been applied to less advanced vessels. This technology is particularly used in the dredging and offshore industries.
Dredgers

Up to 1985 automation on board of dredgers was primarily carried out with the aid of micro-processors, which were installed separately next to the manual controls. Since 1985 it has been possible to combine (integrate) this type of automation with manual controls by using standard Programmable Logic Controllers (PLCs). These PLCs are primarily used for industrial automation and the more advanced PLCs are highly applicable for use on ships. Since 1985 more than 10 systems equipped with PLCs for integrated control and automation have been delivered to the dredging industry.

Initially applications were limited to the so-called cutter suction dredgers, non self-propelled pontoons which are moved forward using anchor lines. The primary job of cutter suction dredgers is to dredge waterways. In this area the automation and control aspects primarily manage the dredging process itself. Since 1990 the integrated automation and control concept has been used successfully for self-propelled dredging vessels, the so-called trailing suction hopper dredgers; into which, in addition to control of the dredging process, the control of the engine room and propulsion are integrated (see figure 4) [5, 11].

Control of the completely automated processes is done via keyboards and video displays (figure 5), through which manual control and servicing can also be carried out. The traditional manual controllers (handles and buttons for several separate functions) have almost completely disappeared.
fig. 4. Integrated Control and Automation on board trailer

The control of all actuators and the reading of sensors is by the locally placed PLCs, which also carry out distributed control and regulation. The link between these local PLCs and the man-machine interface (MMI) on the bridge is secured via a network (with redundancy back-up or not).

fig. 5. Operator console on board dredger.
This network considerably reduces cabling costs and creates a large degree of versatility. The first such integrated system was delivered in the spring of 1990 and consists of 7 PSCs, 2 PCs with four monitors as MMI, and a 10 Mb/s network (figure 4). In 1992 two ships automated in this way will be delivered, including partially integrated navigation systems. This will require increased redundancy (e.g. for the network).

Transport Vessels
The application of the integrated concept for automation and control on board transport vessels is also feasible. An example of this is the "Auxiliary and Oil Replenishment (AOR) Ship" of the Dutch Navy which will be operational in 1994. Here also automation will be provided with the use of PLCs (8 units) and operation and presentation by means of 9 operator stations made up of 9 PCs fitted with 14 screens. Each PLC will offer local operation (also for back-up) and together with the operator stations will ensure:

- propulsion
- adaptive steering control [7]
- engine room control
- auxiliary systems
- cargo/load systems
- loadmaster
- nuclear biological chemical damage control
  (possible at three locations: aft, forward, central control station).

It will be clear that there are also benefits in the incorporation of this type of integrated system for other transport ships such as tankers and ferries.

Safety Aspects
Integrated Control and Automation influences safety on board ships in various ways:

- through the automation equipment directly (reliability of equipment);
- through the functions carried out by the automation equipment (safety functions).

Reliability
The reliability of the equipment is expressed in availability (Mean Time Between Failures, MTBF), the speed with which failures in the system can be corrected (Mean Time To Repair, MTTR), and the influence of failures on the entire operation (incl. redundancy).
No general statement can be made about these aspects because the requirements and possibilities vary per application. In any event a very reliable system can be supplied technically by doubling the systems required. This possibility should be carefully considered for each subsystem to prevent unnecessary costs.

In any case, a reliable (perhaps even more reliable) subsystem can be achieved in an integrated system. Coupling of the various subsystems will in general take place over redundant networks, guaranteeing the transfer of information between the subsystems and the man-machine-interfaces. When compared to a traditional installation, a well-designed integrated system provides the following advantages:

- just as reliable, or more reliable control/automation per subsystem;
- more reliable presentation and control, because these are possible at several locations (back-up via other control consoles);
- quicker detection of defective subsystems via built-in diagnostic systems and a simpler hardware concept;
- quicker repair of defective parts by simple exchange of a limited number of different components (repair by replacement).

Safety
In addition to the greater reliability of the automation and control systems, safety is further increased by incorporating extra security systems (software modules) in the integrated systems:

- control over the operation of the individual sensors through trend analysis and comparing the sensors to one another (checking for possible contradictory sensor data);
- through (semi) automatic trend analysis of the performance of the individual ship's equipment better maintenance can be provided, increasing the availability of the total vessel;
- through built-in checks on operator inputs, mistakes or unsafe operation can be prevented;
- through a combination and presentation of relevant information only, the operator gains better insight in the ship's operations (he is less confused by irrelevant information);
- during breakdowns or emergencies immediately relevant information can be provided which will aid in providing solutions (decision support system);
- through available calculation capacity, extra functionality can be added, such as stability calculations, load calculations, predicted behaviour etc.
The above summation shows that an integrated approach, in addition to operational advantages, also provides benefits in the area of safety, if the correct attention is given to this. A negative argument is that an integrated system can be somewhat more complex technologically, which requires the operator having extra training.

Future Developments

Until today the integrated system approach has been limited in two ways:

- an integrated approach from the automation suppliers by which automation and control form the most important area and navigational elements are being gradually included.
- an integrated approach from the suppliers of navigation equipment in which several monitoring elements of e.g. engine room control (alarms) are integrated, but whereby less attention is given to the real automation and control effects.

In the future navigation, automation and control should be further integrated. This will be easier to achieve with the availability of the Electronic Chart Display and Information System (ECDIS), because this navigation element is also included in a computer [10].

Conclusions

Integrated Control and Automation is already very profitable, especially for ships on which more complex operations are required (e.g. warships, ferries) or on which more complex process control is necessary (e.g. dredgers, offshore pontoons). Because today it is possible to carry out these functions with 'standard' industrial equipment, they are also more economically attractive to less advanced ships, especially if navigational controls can be further integrated into the system.

Special attention will have to be given to operator training including the use of simulators. At the same time standardisation will prevent an excess of operation and presentation concepts being developed and lead to trouble and risk-free transfer of operators. By means of unambiguous controls, the incorporation of security systems to prevent operator errors, on-line diagnostics and decision support systems a safer system will be made available.
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Bridge lay-out, operation and safety

H. Schuffel

Abstract

Trends towards reducing costs of ship operation demand to conceive the bridge as an operational centre for performing both navigational and platform supervisory functions. An automated bridge supports efficient ship operation and makes single handed performance possible, but the need is emphasized for experimental testing of lay-out, mental workload and task performance with regard to safety. This article addresses some design issues, such as function allocation and the testing of performance in a series of simulator experiments. After introducing the ergonomic design process, particularly the process of allocating functions to humans and automatic devices, the testing of ship's bridge lay-out is elaborated. Results show that careful function allocation can lead to an automated wheelhouse concept suitable for safe navigation in landfall conditions. The implementation of ergonomic aspects in the design process is highly effective to reduce human errors. The amount of human error-related events might be reduced with 60%. Questions concerning the effects of monotonous watch periods on operator's alertness need further attention.

Introduction

The number of personnel on board merchant vessels amounts today sometimes to about 16. In comparison with years ago this is quite a reduction. Crew size reduction is a result of the continuing search for efficient ship operation through automation. These developments are based on studies in various western countries to optimize design, operations, maintenance, investments and energy consumption against the criteria of costs, safety and efficiency. Human factors design methods and data contribute to efficient and safe ship operation through adaptation of instrumentation and procedures to human capabilities. Human factors research in particular is directed toward predicting effects of crew size reduction on the quality of system and human performance. The present study, under contract to the Netherlands Foundation for the Coordination of Maritime Research aims at the testing of the ship's
bridge as an operations centre suited for single handed performance.

National maritime authorities show increasing interest in the human factors on board ships because of accidents due to insufficient man-machine interactions. Other civilian and military organisations show for the same reasons interest in the improvement of the quality of work and safety of performance. Some shipping companies have developed surveys to check the performance of maintenance and operational tasks. Classification bureaus, for instance Det Norske Veritas, require training standards, particularly regarding emergency conditions. The US Defense Organisation conducts an extensive programme for the procurement and design of equipment emphasizing human-systems-integration. The policies of organisations is directed to the improvement of the match between human and equipment.

Ergonomic design process

To transform operational need into a system description, human factor design method follows a series of steps, involving mission analysis, function analysis, function allocation, task analysis and performance prediction. The analyses are repeated several times in the course of the synthesis phases of the design process. The analysis of system mission and system functions lead to functional requirements which are the basis of allocation the decomposed functions to men or machines. Finally the analysis of the operator tasks and machine processes give the data for interface and workstation design, to be tested in terms of operator workload and system performance.

The functions to be fulfilled on a bridge, conceived as an operational centre, might be: navigation, communication, propulsion, course control, electricity supply and ship's condition monitoring. In the present study, functions were decomposed to such a detailed level that performance by personnel or equipment could be allocated unambiguously. Each decomposed function was analyzed (Schuffel, Dijkstra, Weeda and Tresfon, 1981) with regard to information source and information processing, control criteria and cations, statistics of accidents (Drager, 1981) and human factors data (Salvendy, 1987).

As shown in Table 1, the results of the allocation emphasized the Officer of the Watch's role as a look-out, decision maker and supervisor of automatons, whereas control functions are limited to set-point adjustment. At the planning level the master can be assisted by computers for optimizing the route with regard to minimal fuel usage, but decision support systems are not yet applicable and have to await further development. At the intermediate level the computer can support monitoring functions. For instance,
the Automated Radar Plotting Aid is superior in detecting and tracking targets on the radar display. The identification of targets however, need the human eye. At the control level the adaptive autopilot can replace the helmsman.

Table 1

<table>
<thead>
<tr>
<th>activities</th>
<th>functions</th>
<th>motor control</th>
</tr>
</thead>
<tbody>
<tr>
<td>perception</td>
<td>information</td>
<td>control</td>
</tr>
<tr>
<td>planning</td>
<td>A</td>
<td>M</td>
</tr>
<tr>
<td>monitoring</td>
<td>A</td>
<td>M</td>
</tr>
<tr>
<td>executing</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>

The expansion of automatically controlled functions and the availability of electro-optical computer controlled displays make the design of workstations for single handed operation feasible. In Figure 1. the mock-up of a future bridge design concept is shown.

Figure 1. Picture of the mock-up of a future bridge design lay-out with a semi-automatic chart table and displays for monitoring navigation and platform functions.
In Figure 2, a sketch of the navigation display is presented. The three levels of information concerning planning, monitoring and executing activities are presented in different colours to enhance overview and detailed information at one glance (Baty and Watkins, 1979). The planning information contains geographical, wave, wind and intended track data. The monitoring information consists of the ship's position and movement status, such as: heading, change of heading, under keel clearance and its change, a ground related velocity vector and echoes of ships, with velocity vectors calculated by the Automatic Radar Plotting Aid automaton. Information at the lowest level shows the rudder deflection and shaft revolutions status.

Figure 2. Navigation display with integrated information concerning planning, monitoring and executing activities. The three levels of information ought to be presented in different colours.
Testing operator's workload and system's performance

Method
The present study is focused on high workload conditions in coastal and congested areas. For these conditions, one of the relevant questions is whether one ship handler (the Officer of the Watch) can cope with the mental workload, maintaining the system performance at the actual average practice level. Mental load is defined here as the degree to which a task appeals to active processing of information; i.e. the number of conscious cognitive operations per unit of time.

The mental load of a primary task can be measured by using a standardized second task that requires active information processing continuously. The procedure is as follows: after training, the performance on the second task is measured separately; next, the second task has to be executed while navigating. The resulting performance reduction on the second task reflects the mental load of the navigation task.

To investigate the effects of automatic equipment on the mental workload of the Officer of the Watch and on the accuracy of navigation, performance of single-handed operation in an automated ship's bridge, the so-called "Bridge '90" has been tested against an average conventional bridge with two and one person control (Boer and Schuffel, 1985a, 1985b; Boer, Van Breda and Schuffel, 1986).

The mental load of the navigation task is expected to be larger in the one-officer-operated conventional bridge compared to a two-officer-operated conventional bridge and a one-officer-operated automated bridge. The main reason is that the design of Bridge '90 has been aimed at technical automation of routine tasks (e.g. position estimation) and optimizing information presentation by integrating relevant parameters on a navigation manoeuvring display (see Figure 2). Hence, as much attention as possible is free for planning and decision making as well as for a proper execution of additional tasks. In the conventional bridge, two officers are considered by maritime authorities to be quite capable of executing navigation and additional tasks. For one officer, however, it is believed that too much time is lost by sampling necessary information and too much attention is consumed by routine tasks to allow a proper execution of additional tasks.

In three simulator experiments, a total of 32 representative watch officers had to follow predetermined tracks in a coastal area with a 40,000 tons container vessel. The visibility range was 5 km, there was moderate traffic density and normal current and wind conditions. Deviations from the predetermined track were calculated as root mean
squared error to indicate accuracy of control. A continuous aurally-presented memory task (CMT) was used to determine the mental workload that the navigation task imposed on the Officer of the Watch. Subjects were asked to memorize four consonants in randomly presented letters of alphabet during seven minutes. The sum of the absolute number of deviations as a percentage of the total number of target consonants was calculated to indicate workload. Three main conditions were investigated.

- A conventional bridge with an Officer of the Watch charged with conning functions, assisted by a tracking officer (condition A);
- A conventional bridge with single-handed watch (condition B);
- Bridge '90 with single-handed watch (condition C).

![Figure 3. Mean percentages of the travelled time that the ship remained within intervals of 100 m from the track.](image)
Results

Navigation accuracy. In Figure 3, percentages of the time (averaged over tracks and subjects) that the ship travelled within intervals of 100 m from the intended track are given for the three conditions. In Table 2 the results of t-test are presented. From Figure 3 and a statistical analysis it becomes clear that navigation accuracy differs significantly among the three conditions. Navigation performance is superior in Bridge '90. Path width remains within 400 m for 95 per cent of the time. In contrast, two-officer operation in the conventional bridge results in a comparable path width of 800 m, and one-officer operation even in 1200 m.

Mental load. In Figure 4, mean error percentages of the CMT of the control and experimental conditions are presented. The results of a statistical analysis show no significant differences between the mental load of the navigation task in the two-officer-operated conventional bridge as compared to Bridge '90. Perhaps even more surprising is that for these conditions (A and C), only a slight, and not significant, deviation from the control condition can be observed. This reflects that the mental load of the navigation task is quite low. In contrast, the mental load of the navigation task in the one-officer-operated conventional bridge (B) is significantly higher as compared to the control, A and C condition. This difference suggests the presence of attention-demanding task components (notably position estimation).
Discussion
Observed differences in navigation performance and mental load of the navigation task can directly be attributed to bridge design on one hand and number of officers on the other hand. As mentioned before, the two-officer-operated conventional bridge served as standard against which other conditions were tested. As far as Bridge '90 is concerned, it may be observed that due to accurately and continuously presented position feedback, navigation performance is superior as compared to the other conditions. As a consequence, navigation accuracy is improved. The more accurate navigation in Bridge '90 does not seem to increase the mental load of the navigation task. Apparently, the greater frequency at which actual position is monitored as well as decisions on control actions resulting from these observations do hardly require attention. This conclusion is supported by the fact that CMT error percentage in Bridge '90 does not differ from the error percentage in the control condition.

Possible reduction of shipping accidents

Method
The causes of 100 Netherlands shipping accidents (1982-1985) were analyzed with regard to the question whether an automated wheelhouse concept could have prevented these accidents (Schuffel, 1987). Events necessarily contributing to the 100 accidents were categorized in an activity/system element matrix and in an activity-function matrix. In this exploratory study, three experts (an ergonomist, a nautical officer and a psychologist) estimated on the base of fault-tree analysis, whether the automated wheelhouse concept would have affected the occurrence of the events. It was expected that differences between the number of events related to accidents with conventional ship bridges and to supposed accidents with the advanced automated bridge, would reveal advantages and disadvantages of the function allocation process and the inferred automated wheelhouse concept.

Results
The results showed that 276 events were involved in the 100 shipping accidents. This number of events consisted of 209 events related to human errors, 24 related to hardware errors, 9 related to procedural errors and 34 related to environmental errors. The automated wheelhouse concept would have reduced the amount of 276 events to 88; a reduction of 68%. Regarding the reduction of the number of events related to human error only, Table 2 provides an overview. The
209 human error-related events were reduced by the automated bridge with the number of 162 to a remnant of 47 events.

Table 2
Reduction of the number of human error-related events due to the automated wheelhouse concept.

<table>
<thead>
<tr>
<th>activities</th>
<th>perception</th>
<th>info processing</th>
<th>functions info storage</th>
<th>handling</th>
<th>rest</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>voyage planning</td>
<td>1</td>
<td>27</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>voyage execution</td>
<td>19</td>
<td>65</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>88</td>
</tr>
<tr>
<td>communication</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>monitoring tasks</td>
<td>0</td>
<td>28</td>
<td>9</td>
<td>0</td>
<td>1</td>
<td>38</td>
</tr>
<tr>
<td>total</td>
<td>22</td>
<td>124</td>
<td>15</td>
<td>0</td>
<td>1</td>
<td>162</td>
</tr>
</tbody>
</table>

Discussion
The results showed that the automated wheelhouse concept might be highly effective to reduce human errors. Hardware and procedural errors might be affected to a lesser degree. Environmental factors, including communication and information exchange between ship and shore seem to be nearly affected. This emphasized that the effectiveness of the automated wheelhouse concept is, of course, also dependent on the organization of the shipping company and the maritime authority.

The distribution of the events over activities and functions shows that in particular errors could be prevented in the performance of the information processing functions. With regard to the simulator experiment results, these improvements are interpreted as the improvements of navigational performance supported by the semi-automatic chart table, the integrated APRA-maneuvering display and the availability of navigational auxiliary systems information at one position.

Conclusions and recommendations
It has to be emphasized that the investigations concerned a feasibility study, primarily concentrated on human performance and mental workload of the Officer of the Watch. It is obvious that a number of other important items have not been addressed. On the one hand, the effects of monotonous watch conditions on the operators' alertness and the effects of the change in the task structure - from active manual control to passive monitoring activities - on the operators' skill and interest in the job, need more
research. On the other hand, the progress of technological development and the reliability of automatons and human beings is assumed on the basis of similar developments in aviation. Although the suggested technology is not extremely advanced, applications of electro-optical computer-controlled displays and the related chain of sensors, as well as data preprocessing and data transmission is not widely spread in the maritime field. Currently undertaken projects, such as the development of the electronic chart, indicate that progress may be expected here. It is speculated that the annual number of accidents will decrease when an automated, ergonomically designed, bridge concept is put into practice. The costs of studies and the investment due to new equipment are negligible (presumably 1 per cent of the design costs), in comparison with the estimated prevention of injury, loss of life, and the saving of environment and capital.

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Abstract

Naval ship systems are highly automated, such that the vessel with her complement is expected to be fully operational over a complete mission. Lessons learned in a hostile environment have influenced the design of modern naval ships remarkably. The evolution of automation aboard shows that the state-of-the art in technology is applied in great extent to enhance the prospect of survival. Expert systems in development will contribute to the effectiveness of the crew in hazardous and stressful situations. Analysis of the role and effectiveness of crew members in damage scenarios is still required for getting the right mix between crew and technique.

Introduction

This paper aims to highlight the need for automation in cohesion with safety aspects aboard naval vessels and considers the next subjects:

- non-automated naval ships in a hostile environment: the Falklands experience,
- evolution of platform system automation in the Navy,
- contribution of automation to naval ships' safety.

It is of interest to be informed about the evolution of ship systems automation in the Navy and its contribution to ships' safety because automation on one hand reduces the complement and on the other hand provides a less vulnerable ships' platform.

Moreover it is justified to address the question: "Why do Western navies spend a lot of their budget on development of ships' automation, and why is this unique compared for instance to merchant naval vessels?".

Before giving the answer it is of interest to present a factual record of a remarkable story about naval surface ships of the Royal Navy in an out-of-area operation for retaking the Falkland Islands, nearly ten years ago.
Non-automated naval ships in a hostile environment: the Falklands experience

Experience of Operation Corporate ships in the South Atlantic in 1982 proved conclusively that one of the most serious aspects of battle damage is smoke. Unless it can be localised, contained and subsequently removed the task of damage control is magnified out of all proportions to a point in some cases where recovery becomes impossible.

If one has experienced the horror of thick black smoke in the ship one will understand it is vital to have the technical answers on questions about smoke containment and clearance.

Under air attack HMS Broadsword was bombed starboard aft above the propeller guard. The bomb penetrated the ship and deflected up through the flight deck causing extensive damage to communication systems and services, including hydraulics, high pressure air, electrical systems and the shipboard helicopter. Damage control parties had to contend with smoke fumes and flooding, the restoration of steering control and repairs to services and systems. Apart from loss of the helicopter, damage control minimised the effect on fighting efficiency.

In course of an operational task an air launched Exocet missile struck HMS Sheffield midships starboard side, tearing a hole of about five square meter in the ships side. The fire extinguishing water system was severed, fuel oil tanks were ruptured, damage extended throughout the midships section. A fireball caused a number of secondary fires and thick black smoke from the unspent missile propellant fire spread rapidly. Fifty per cent of the lighting and remote control of machinery was lost.

Within minutes of the impact the machinery control room, machinery spaces and bridge had to be evacuated. Damage control activities were handled by the forward and aft fire/repair party posts. The main fire pumps spread over the ship could not be restored or subsequently stopped or were out of action, and the chain broke on the emergency fire pump. Additional equipment was obtained from other ships but regrettably the ship was lost. The lessons learned are again that smoke containment and ready-for-use fire fighting systems are of vital importance.
As part of the task force operating in the South Atlantic, HMS Coventry suffered devastating bomb damage port, forward and midships with cannon damage along the port side of the waterline. The forward auxiliary machinery spaces flooded rapidly. As the angle of roll increased, damage and penetrations in the ship side, decks and bulkheads submerged. As the depth of the ship increased so did the rate of flooding.

Damage control parties faced a formidable task under appalling conditions. Shock, fire, smoke and the South Atlantic thundering into the ship. Regrettably HMS Coventry was lost.

Early morning in the South Atlantic while on transit from coastal areas, an Exocet missile hit HMS Glamorgan and detonated in the vicinity of the hangar. A nearly five square meter hole was blasted in the hangar deck. The helicopter exploded and a major fire developed in the hangar. The galley was devastated, a weapon magazine started to flood and with half the ships' power lost the ship heeled twelve degrees with an increasing amount of water from firefighting and fractured watersystems.

The answer to the stated question is quite obvious and two-fold:

- the threat environment in which naval ships operate is severe and hostile, as a direct consequence of the tasks or missions these vessels have to perform;
- as modern naval ships are relatively small in size and, as a consequence, a high number of people live in crowded circumstances surrounded by explosives, combustibles and highly toxic chemicals, any incident will lead to a high number of casualties.

Our Navy philosophy is that extensive automation will enable naval ships to limit damage and the number of casualties and will allow the complement to fight with the ship longer and hopefully more successfully.

In the next part of this paper only the Royal Netherlands Navy is involved, recognizing its prominent role in the field of automation compared to other NATO navies.
Evolution of platform systems automation in the Navy

With regard to the electronic technology introduced aboard naval vessels only platform systems are being considered, ignoring systems related to the payload. Platform systems are concerned with propulsion, electrical power generation and distribution, safety and support, representing a quite heterogeneous technical system structure. However there is a strong demand for integration of propulsion and electrical power plant in future naval ships, changing over to a total energy system concept.

The explosive rate of new developments in high technology, especially in electronic computerized systems, has been a major factor in influencing designers of control and monitoring systems for the maritime industry already for many years.

Since 1975 this has been particularly true, where worldwide and ocean-going naval vessels are concerned. They rely on the quick response of man-machine interface (MMI) systems and operational reliability for their survival in hazardous and stressful situations.

These system outputs are in remarkable contrast with the relatively sluggish human reactions and expertise that have been demonstrated in the past. For example steam plant for propulsion and electrical power generation, which required a crowded environment with fully manned machinery spaces, having all human resources available.

Indeed, events now seem so squeezed in the "space-time" dimension as to override man’s ability to react quickly enough. Even though, one must concede, this integrated system "intelligence" is by no means better than, nor any substitute for, the parent human intelligence, on which, after all, every decision-making process ultimately rests.

The evolution of ships' platform occurs under the spur of need for obtaining utmost efficiency from exploited platform systems by reducing operator’s involvement for routine procedures, eliminating operator error under stress condition, and improving human factor aspects. A secondary aim is the achievement of reductions in complement, as costs of personnel have been demonstrated to be far the greatest in annual ships’ running expenditure.
Let us now concentrate on the ships' control centre (SCC) of our standard frigates built between 1975 to 1984 with the technology available at that time, having unmanned machinery spaces and a watch keeping shift of minimum two to maximum four or five watchkeepers (including roundsmen).

Panel design is such that almost all information is presented simultaneously. Alarm- and warning annunciators and indicator lamps are applied, in system groups wise through coloured frames, adhering to the all-dark principle. Control panels for propulsion, electrical power, auxiliaries and damage control are incorporated.

During the construction of the frigates the idea arose to modernize the SCC, by implementing a new MMI-concept using visual display units (VDU's) and terminals. Due to contractual obligations these ideas were not implemented. This alternative SCC-concept came alive again at the beginning of 1980, when the ocean-going WALRUS-class submarines were developed.

An integrated control and monitoring system (ICMS) in today's naval ships enables the watchkeeping crew to operate the ship's platform through a permanent attended centralized SCC as the nerve centre and under all, except damaged, conditions with unmanned machinery spaces (i.e. Lloyds UMS). All routine and/or manpower consuming procedures to operate and to keep platform systems operational, are automated to maximum extent.

The WALRUS-class submarine has also unmanned machinery spaces and an ICMS, containing a number of automated control systems, e.g. for charging and monitoring main batteries, for diesel-electric plant control and for trimming and ballasting.

A distinguishing difference with the fore-mentioned frigates is the application of digital technology.

The WALRUS-class ICMS provides a concentration of controls and monitoring around two operator positions at portside in the command and control centre, introducing in the Navy VDU's with mimics for monitoring and manipulating platform components. On mimics the actual status of platform systems is presented.
It can be said now, that because of the application of an ICMS, the reliability and controllability have improved to a great extent.

In harbour, the WALRUS-class platform control watchkeeping duties are performed quite satisfactorily by teams, containing crew members not belonging to the marine engineering department. This routine has shown that the use of mimics on VDU’s as man-machine interface of the ICMS can be very efficient and extremely user-friendly, provided the human factors aspect of the design is well thought out [1]. And finally, the ICMS has enabled the WALRUS-class submarine to be operated with 25 per cent reduction in marine engineering staff compared to its predecessor (with manned machinery spaces).

The WALRUS-class philosophy and the specification used in its design and production, have been applied in the design of the newest generation surface ships in the Navy. More digital techniques are being applied and in contrary to the WALRUS-class submarines predominantly VDU’s and terminals are used.

An automatic data processing system informs the operating crew and management staff about the actual status of platform systems and enable operator(s) to control these systems in such a way that the actual operational requirements are being maintained. Immediate countermeasures against damage or fire hazards are initiated or controlled by control centre operator(s), in order to minimize extension of damage or fire.

Under normal sailing conditions (in the peacetime role) it is possible to operate ship systems permanently with one operator only in the SCC and direct bridge control of propulsion, steering and stabilization.

Under wartime conditions the SCC is still manned and operated by maximum of five operators, again with unmanned machinery spaces.

In addition damage control stations are arranged fore and aft in the ship, accessible from open deck and given entrance into the ship for firefighting and repair parties. The stations are equipped with an information system for all necessary related data, which minimizes voice communications between action stations.
The SCC control and monitoring system is moreover equipped with management and faultfinding assistant functions.

Contribution of automation to naval ships' safety

The status quo in the Navy:
Aboard naval ships there are quite a number of hazardous and explosive compartments, such as ammunition and flammable liquid stores. To cope with these risk areas the compartment temperature rises and the presence of explosive gases are monitored, given an early warning or detection in the manned ships' control centre and in damage control stations fore and aft in the ship.

Complementary detectors are suitably arranged throughout the ship for early detection and alarming of arising fires in ships' ventilation zones, being again centralized monitored in the SCC and damage control stations.

To deal with unacceptable water levels, in contrast to the rules of Lloyds Register of Shipping, all bilge wells below the waterline are monitored and alarm arises in the above mentioned control centre.

To control ships' water- and gastight integrity the position of water/gastight doors, hatches and damper valves is centralized monitored and/or controlled. Alarm arises if a selected integrity condition, depending on ships' readiness state or environmental conditions (e.g. high sea states causing green seas), is occasionally broken.

To prevent contamination from N(uclear)B(iological)C(hemical) warfare inside the vessel actual closing down of the ship within one minute is remotely achieved from the control centre. This gastight condition can be sustained for at least 24 hours, for which the ship is arranged in so called citadels. In this citadel constant overpressure relative to the ambient condition is automatically controlled and maintained by its NBC air filtration system.
Complementary to these provisions it is also possible to remotely control ventilation (sub)systems with their fire/smoke dampers in such a way that the fire and/or smoke is contained within a limited envelope with defined boundaries and supply of fresh air into this space is choked. These facilities can allow for smoke or gas clearance after fire extinguishment.

Main fire extinguishing systems are remotely controlled and monitored with regard to pump operations and reconfiguration of system lay-out, assuring this safety system stays readily available for usage.

Electrical power generation and distribution are automatically controlled and monitored, allowing for any reconfiguration or, after degradation of automation, for local control. Uninterrupted power supply to preferential consumers is assured to the greatest possible extent.

Finally an automated calculation system for intact and, in particular, damage stability, using input data from tank level and draught indicating system, has been made available. Different hull flooded conditions or the influence of free fluid surfaces above waterline (due to e.g. excessive fire extinguish water) can be investigated and appropriate action, such as counterflooding, can be evaluated.

For all these automated systems it is emphasized that the majority of the necessary control is initiated or executed from ships' control centre; the remainder of actions or countermeasures to be handled are co-ordinated from this nerve centre too.

**Developments in the very near future:**

Recently the Royal Netherlands Navy has, in close cooperation with TNO Physics and Electronics Laboratory in The Hague, carried out a feasibility study for a decision support system, called DAMOCLES, with respect to NBC and D(amage)-control, based on artificial intelligence techniques.

This study has proven that such a system is viable [2]. Consequently, a project definition phase will be started for design and realization of an advanced naval damage control expert system, announced as ANDES.
The main reasoning behind this plan is that ANDES will lead to a substantial improvement of NBCD-management and ships' safety in general, resulting in a greater survivability for the ship and her crew in a hostile environment, in time of tension or in the peacetime role. Priority will be to keep the ships' fighting capability intact and the ship afloat for at least battle damage repair outside the hostile area.

Important aspects be taken into consideration are:

- faster and more effective execution of NBC- and Damage control (inclusive stability and buoyancy control), becoming less dependent on specific knowledge and skills of ships' crew;
- to maintain the quality of NBCD-command and control with a reduced complement and increased complexity in future naval ships;
- uniform and consistent application of NBCD-procedures;
- considerable reduction in the influence of the factor stress on management behaviour.

The aim of ANDES is to assist ships' damage control staff in the management of fire fighting, structural damage repair, ships' stability restoration and buoyancy recovery and NBC-warfare protection, using input data from the existing information processing system for platform systems.

The functional requirements for the system can be summarized as follows:

- to advise in the above mentioned matters, depending on the state of readiness for the ship, by collating relevant system status information, predicting consequences of (battle) damage and planning countermeasures, and surveying the effects of countermeasures;
- to present technical system parameters and in-depth explanation of advice given;
- to evaluate necessary operator system interference by simulation and to present the results of these simulations;
- to execute advice after operator's authorisation.
The operational requirements to be met are:
- application of artificial intelligence techniques;
- hardened components (against shock loading and electromagnetic pulse);
- real-time operator response;
- ship-independent performance.

It has been proposed to have ANDES available for implementation aboard within a few years.

After the Persian Gulf war experience the Navy is also doing research for a chemical agent detection and alarm system; a nuclear radiation detection and alarm is already applied in the Fleet.

Finally the Navy is working hard for environmentally sound ships, offering a new challenge for automation as far as practicable.

Conclusions

Naval ships' systems are relying on automation for their survivability in a hostile environment; systems are highly automated, such that the ship is expected to be fully operational over a complete mission.

The automation implemented aboard is following the state-of-the-art in technology, available up to date the contract with a shipbuilding yard is signed on basis of a detailed ships' specification. A dedicated automation programme thereafter can only be successful if, in parallel to the principle lay-out definition of platform systems, ships' functions and operation task analysis has been performed by the Navy in advance.

There is interest in the development of advanced technology, such as intelligent knowledge based systems. The application can displace and/or support many of the operational and non-operational tasks previously undertaken by the crew. A paperless ship is even being considered with confidence. As ships' automation has to be affordable there is the strong tendency to apply commercial available hard- and software in future naval ships, meeting as far as practicable the Classification Societies rules and regulations.
More detailed analysis of the role and effectiveness of the crew in damage scenarios is still required, making human engineering (man machine interface and task analysis) particularly important for getting the right mix between crew and technique [3].

References


4. Design of Ships and Machinery

4.1 Safety in Design of Ships

4.2 Evaluation of Design Parameters

4.3 Design of Machinery Installations

4.4 Machinery Installations Emissions
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Abstract

The goal of the paper is to provide a sound base for handling safety problems. Such problems exist with regard to the development of safety standards as well as to reactions of the public to ship accidents. The paper describes basic concepts available for the provision of safety in ship design. It further deals with concepts for answering the question "how safe is safe enough".

Introduction

With regard to the safety of ships we may notice several different and mostly contradictory points of view: For the head of the design department of a shipyard no safety problem exists; he just sticks to the safety regulations without compromise and nothing is left for him to bother about. For another designer the only problem with regard to safety is how to comply with the regulations (or rather how to satisfy supervisory bodies) at minimum costs.

For some people any accident is a proof that the safety requirements are deficient. Especially, when a major disaster is overplayed by the media, the public overreacts to it and politicians push regulatory to produce new safety regulations in order to appease the media. On the other hand there are shipowners who claim that there are too many safety requirements or that they are exaggerated.

Many researchers are of the opinion that safety problems are caused by incomplete knowledge of physical relationships. This opinion is based - often unconsciously - on the idea, that perfect physical insight would lead to total safety. Since total safety does not exist in our world the actual question is "How safe is safe enough", and this question cannot be answered by physical reasoning. The situation is ably characterized by a word of the philosopher Churchman (1961): "Probably the most startling feature of twentieth-century culture is the fact that we have developed such elaborate ways of doing things and at the same time have developed no way of justifying any of the things we do." In other words, there is a discrepancy between the level at which we treat physical relationships on the one hand and the level at which safety per se is handled on the other hand.

In the following I will try to indicate some ideas for a methodology of ship safety. I shall start with the description of different concepts for the provision of safety.
Then I shall look at the question how to find the right level of safety.

Safety Concepts

Shipbuilding is one of the oldest technologies. Since the beginning the safety of the ships was the concern of seafarers and shipbuilders. The first and simplest concept to provide safety was to build the ships according to the experience-based description of the hardware. The oldest example is Noah's ark: It was built according to the given description with the result, that its stability, strength etc. were sufficient. Until the 19th century safety against capsizing was achieved by giving the ship proper proportions. Until not long ago the rules of Classification Societies provided sufficient ships strength by the description of structural elements in dependence of the main dimensions of the ship. The disadvantage of this hardware-based concept is, that progress was possible only in very small steps in order to omit risks.

The second concept to provide safety is not to describe the hardware but to require certain physical characteristics of it. As an example the requirement of minimum righting levers for providing safety against capsizing may be mentioned. Because the introduction of welding gave more freedom in designing the structural elements of ships the direct description of such elements in the classification rules was replaced by giving the section modules. This concept gives more freedom for the design than hardware requirements. But with respect to the safety philosophy the concept of requiring physical characteristics is not different from the hardware concept. Both concepts neither define safety nor do they allow the quantification of the achieved level of safety.

The necessity to deal explicitly with safety arose with the introduction of big electronic systems and with the development of spaceflight. Thereby safety is defined as the probability that a certain unwanted event does not occur during a given time. It is of interest that an - although simple - application of this concept has been proposed by a naval architect: Sir Wescott Abell (1919) showed how the "odds on" for surviving a damage can be calculated. At that time the professional community was not yet in the position to really understand and to appreciate this idea. More successful was a paper by Wendel (1960) which received worldwide interest and initiated the development of the first probability based safety regulations for ships, i.e. the Equivalent International Regulations on Subdivision and Stability of Passenger ships adopted 1973 by the Assembly of the Intergovernmental Maritime Consultative Organisation. Now the probabilistic concept of safety plays an increasing role in the design of ships and their equipment and machinery.

The three concepts of providing safety have been described in historical order. But one must not conclude that the older concepts have become totally obsolete and that only the probabilistic concept is still up to date. All concepts will keep their range of application. E.g. in order to build safe stairways it is completely sufficient to describe the hardware as hand rails, button plates for the steps etc. There will always remain cases in which the application of the probabilistic concept is not
possible, either because of the lack of data or of too complicated relationships. Then the concept of requiring physical properties may solve the problem, especially when thereby the theoretical background of safety is kept in mind.

**How Safe is Safe Enough?**

Safety assessment by description of hardware is based on experience. Describing safe hardware includes the implicit provision of a certain safety level which has been reached during a trial and error process in the past. The same holds true for the concept of requiring certain physical properties in order to achieve safety. But this concept allows some extrapolation of the experience gathered in the past.

The probabilistic safety concept urges the use of explicitly stated safety levels. At first sight it seems logical to always choose the same level of safety, i.e. a level which has proved satisfactory in the past. But this would be justified only in cases, in which the risk source, the benefits of taking risks, the familiarity with the risks etc. are similar, because for different situations the existence of different acceptable risk levels (or required safety levels) can be observed.

The explicit assessment of safety by probabilistic methods seems to be especially suited for situations where we meet new types of risks produced by new and unfamiliar technologies. These are situations in which the answer to the question "How safe is safe enough" would be of most interest. Unfortunately, up to now there exists no generally accepted method to find such an answer. In some cases it might be helpful to consider safety not as an end but as one of the means to reach a goal in a more comprehensive context. This procedure might be called system approach to the determination of the proper safety.

When the proper safety is to be determined for cases which do not involve loss of or damage to human life the problem can be solved by economic considerations. In order to achieve more safety one has in general to spend more money. At the same time the expected loss is reduced. The optimal safety level is that for which the present value of costs and expected losses is minimum. In order to get useful results the random time to the occurrence of losses has to be taken in consideration. For a couple of redundancy problems methods for calculating expected present values have been developed by Krappinger (1986). When using this concept difficulties can arise when the failure probabilities are low and the losses in case of failure are high. In such cases the amounts of losses would have to be replaced by their von Neumann / Morgenstern utilities (Krappinger 1971). But the utility approach gives rather explanatory results than actual predictions of the optimum safety.

When human lives are at risk there is no point in applying economic considerations. An example how to proceed in such a case has been given by Abrahamson (1962). His procedure is now known under the name "Minimization of the total mortality". His concern was the optimal structural safety of ships. From statistics of fatal accidents in the Norwegian merchants fleet he estimated that only 10 per cent of all accidental
deaths are caused by structural failures. In order to increase the strength of the ships their steelweight has to be increased. The increase of steelweight reduces the cargo capacity of that part of the fleet which consists of deadweight ships. From economic considerations it can be concluded that the reduction of the cargo capacity would be compensated by increasing the number of ships rather than by increasing the size of the ships. For the increased number of ships with higher structural safety the number of accidents due to structural failure would decrease. The number of fatalities in connection with cargo handling would remain the same and the number of fatalities from all other causes would increase corresponding the increased number of ships.

In addition to the above mentioned fatalities Abrahamson took into account the fact, that the production of steel claims its victims at all stages, from the time the ore and coal are mined until the steel is built into the ship. From statistics this number of fatalities can be estimated as function of the steelweight. If the sum of all numbers of fatalities is drawn vs. the ship weight (or the structural safety) one gets a curve with a pronounced minimum. This minimum indicates the optimal structural safety.

The merit of the above reasoning is rather the insight, that the requirement of exaggerated safety can lead to the contrary of what is aspired, than the numerical value of the optimum. This can be explained by the fact that neither the considered system is comprehensive enough nor that the goal is really the ultimate one. E.g. instead of varying the structural safety only one can think of the variation of other safety provisions additionally in order to influence the total mortality. As an ultimate goal the minimization of the total mortality is not sufficient. The real end could perhaps be named "quality of life", but this can not explicitly or quantitatively be expressed. The idea that the minimisation of the total mortality has to be preferred to any other goal does not match the human nature.

Concluding Remarks

It is obvious that my paper contains no distinct prescription how to design ships with proper safety. But I hope that it exhibits a certain systematic of the safety problem which should be helpful to omit the confusion which is reflected by the points of view regarding safety mentioned in the Introduction.

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Abstract

There are many standards concerning ship building and they are more or less practically utilized. For all standards, safety is one of the most essential matters to deal with. In this paper, the builder's standard and its contribution to the safety are discussed from a shipbuilder's viewpoint. The authors review its background and the factors which influence the standard and explained that the builder's standard has been revised and keeps on changing according to the change of the rule requirements, owner's standard, technology advance and social requirements such as environmental protection, labor problems, etc. The merits and future subject of the standard are also discussed with some examples. It is concluded that the standard is always aiming at the highest quality within the allowable cost considering the practical effect and so that the standardized ship is the practical solution to achieve high safety efficiently.

1. Introduction

In recent years, ship's reliability becomes much more important from the viewpoint of marine safety and environment. Many standards concerning shipbuilding including international and each country's maritime regulations, requirements of classification society, etc. have been and still being "up-graded" to increase the ship's reliability. Such rules have been discussed, settled and become mandatory officially and their contribution to the safety do not need to be discussed.
On the other hand, there are other standards, which are not open to the public, than the rules mentioned above. They are ship owner's standard and ship builder's standard. The published rules or ship owner's standard indeed cover the essential part of ship building, but their portion is small and most of ship designing and building technology are established as the builder's standard.

In this paper, the builder's standard are discussed taking container ships for example.

2. Builder's standard

2.1 Basis of safety

In the long history of ship building since human beings made a first "ship" of animal's hide or log, ships have been built without any rules other than builder's own standard except very recent era. It is only in this century when so-called "rules" were born one after another as shipping business grew up rapidly and demands for safety increased.

Most rules only describe "philosophy to achieve safety" and many details are still according to the builder's standard. Builders have made their standard through "precious experiences" in order to keep safety. The builder's standard is considered to be the basis of the safety.

2.2 Factors

There are many factors which affect the builder's standard and they are categorized in two types; external factors and internal ones.

External factors:

- Rule

Principally, the philosophy of the rule is the same regardless of flag and class and ideally we can prepare one standard which fulfill all rules. But there are often the cases that each rule's requirements are somewhat different in detail because each rule deviates around the center of the philosophy. For such cases we have had to prepare the standard according to each rule's variation.
• Owner
Each ship owner has each operational standard. It is practically impossible to prepare the “all-mighty” standard that satisfies all ship owners because their requirements vary too widely. So, we have made several standards for one subject and we cope with the difference of owners by combination of such standards.

• Ship’s type
The difference of ship’s type is the difference of cargo which the ship carries. So, the different standard is prepared for cargo part according to the ship’s type. But, other major part such as accommodation, engine, electric, etc. can be dealt with by common standard regardless of ship’s type.

• Subcontractor
We require our standards which are different from or added to the subcontractor’s standard according to their technical potential and experiences. So, you can find equipments which are same type and made by same maker but somewhat different because they are ordered by different shipyards.

Internal factors:
• Yard’s facilities
We can’t do anything beyond our yard’s facilities. For example size of the blocks are limited by the size of our workshop house and crane lifting capacity. We have made our standard to utilize our facilities most efficiently.

• Technology advance
We’ve been reviewing and up-to-dating our standards in order to make use of technology advance. For example, finite element method and computer fluid dynamics in design stage and automation and welding technology in building stage.

• Experiences
We have many feed backs to assure or revise our standard through many building experiences. In other words, our standard is made of our experiences.
• Labor environment
  There are some items which could be done easily in the past but have been getting
difficult at present because its labor environment is too bad from workers' health
point of view. For example, painting, grinding and so on. We have to revise our
standards to reduce such works.

2.3 Examples

1) Estimation of ship speed and power
   Shortage of design speed causes adverse effect on not only operation cost but also safety
   considering that it will end in tight schedule without appropriate margin. Each builder
   has established the standard including tank test method to estimate ship speed & power
   through experiences. Especially as for container ships, it needs many experiences to
   achieve high accuracy because ship speed trial is usually conducted in trial condition
   where the draft and trim is far from designed load condition.

2) Shape of hatch corner
   We have a standard of hatch corner shape to relieve stress concentration as shown in
   Fig.1. This standardized shape is composed of two series of arc to approximate ellipse
   which is proved most effective for stress relief. This standard has been established by
   theoretical analysis and verified by model and full scale measurement.

3) Snip end for stiffner
   Fig. 2 shows arrangement of horizontal stiffener on bottom side girder. There are two
   types of the arrangement: One is that stiffener is arranged continuously and passes
   through floors as shown in Fig.2-type A. The other is that stiffener is snipped at each
   floor and does not pass through floors as shown in Fig.2-type B. Although type A was
   generally used before, type B has been proved to have sufficient reliability depending on
   strength requirement. Considering productivity and design condition, type B is normally
   used in our yard.
4) No. of paint coat
We had painted thin coat many times in the past. But it has become practically difficult due to shortage of paint workers. This phenomenon urged the progress of paint material that can be painted thicker and technology of painting thick. And it has ended up as the standard by which we can paint as two times thick as before.

5) Tin free paint
Self polishing type paint has swept the whole world with its particularly superior antifouling characteristic since it had appeared in the last 1970's. And all the ship owners and the shipbuilders used it as a standard. But in the late 1980's, organotin compounds contained in antifouling paints were considered to be a problem as the pollution of marine environment. The shipbuilders' association of Japan has discussed and finally decided the restriction on the use of antifouling paints containing Tributyl Tin (TBT). After that TBT compounds were designated as class 2 specified chemical substances under Japanese law and it means that it is practically prohibited to use antifouling paints containing TBT in Japan. From the above, Japanese shipbuilders take tin free paints as a standard.

6) Polyethylene lined pipe
In Japan, a polyethylene lined pipe is popularly used as the sea water pipe in engine room. We have used a galvanized heavy gauge pipe before but we now use the polyethylene lined pipe as a standard because it is more reliable and it is lighter and then easier to handle. This standard has become practical by advanced lining technology.

3. Considerations in builder's standard

3.1 Merit
Merit of the builder's standard is that it assures high quality by standardization as follows:

- High reliability proved theoretically and empirically
- Easy quality control
- Improve workmanship
- Quick and easy feed back in case of any trouble
3.2 Building cost and standard
Builders have made their standards not only to fulfill various external requirements but also to utilize their design and building capability most efficiently. So, it naturally results in the lower building cost.

For example, the building cost of container ships of almost the same size but built in different age are compared in Fig. 3. It is clearly shown that wages per person has increased about 4 times while the cost has increased about 2 times. Furthermore, considering that the number of containers loaded on the same length container ships has increased about 2 times, the cost per container has not increased even though several international safety requirements are added. It was possible because builders made and kept on revising their standards making use of technology advance in various field in order to suppress the building cost while improving the quality.

There is some criticism that says shipbuilders changes their standards to lower ones only in order to reduce their building cost. Builders should have to reconsider the situation that causes such a criticism. But, on the other hand, we would like the critic to understand that such changes is not possible until the quality should be at least kept as same level as previous standard by technology advance or improved quality control method.

3.3 Future subject
We have tried to introduce new material and equipment. Although some of them become normally used, it takes long time in general until such new products are easily accepted because marine use condition is very severe and shipping business is rather conservative.

But, technology advance is more remarkable in these days and so-called high-tech products are coming into the world one after another. We think it is necessary for us to make more use of them in order to "evolve" our ships. Especially as to marine environmental protection, prevention from oil pollution should be old theme and we will have to make our standard incorporated with such new technology being under study as reduction system of NOx & SOx in exhaust gas and anti-fouling system with conductive paint.
4. Conclusion

It can be said that the shipbuilder's mission in economy is to build ships which are as safe as practical and cost as low as possible. These two factors are apt to contradict each other but the builder makes every effort to make them coexist. Through such experiences the builder makes their standard. In other words the builder's standard is the very solution to this everlasting theme.

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Fig. 1 DETAIL OF HATCH CORNER

Fig. 2 BOTTOM SIDE GIRDER STIFF.
The year 1970 = 100

Fig. 3 COMPARISON OF BUILDING COST
Safety of tailor made vessels

J.W. Huisman

Summary

This paper deals with the safety of Owner designed vessels. An outline is given about the rule making procedures, as rules are the basis of the safety of a vessel. Some of the differences between Yard designs and Owners designs are pointed out. In more detail, the design of the Ultimate Container Carrier is explained.

Introduction

Safety on board of a vessel is a condition that is the result of people, hardware (inclusive design), organisation and procedures. This paper deals with the difference between "standard" ships (designed by yards) and "tailor made" vessels (designed by owners). The difference between those two shiptypes is the hardware. For that reason this paper will discuss the hardware part of safety only. Safety hardware on board of vessels is installed because it is mandatory by (inter)national rules and as a result of operational experience.

Rules and regulations

The majority of safety hardware is prescribed in (inter)national rules. Most rules are made by the International Maritime Organisation (I.M.O.), a specialized agency of the United Nations, dealing with maritime affairs.

In order to understand the value of the mandatory safety hardware on board of ships it is necessary to understand the working procedures of IMO.

The governing body of IMO is the Assembly, which is assisted by a council, several committees and many subcommittees, working groups and drafting groups. The paperwork is coordinated by a Secretariat with some 300 international civil servants.

The most senior committees are the Maritime Safety Committee (M.S.C.) and the Marine Environmental Protection Committee (M.E.P.C.)

In order to achieve its objections, IMO produces conventions, protocols, codes and recommendations. After a ratification procedure IMO instruments become mandatory; in most cases they are implemented in domestic legislation.

1) The views expressed in this paper by the author are not necessarily those of Nedlloyd Lines.
The basic international convention related with matters of maritime safety is the SOLAS 1974 convention (amended). Although IMO describes itself as a technical organisation, the last 10 years politics have gained influence drastically. This means that technicians propose or defend political issues in order to safeguard domestic political aims.

In some submissions to IMO the improvement of maritime safety is of minor importance; they are instruments to gain votes.

The IMD bodies are formed by the delegations of National Maritime Administrations, international governmental and non-governmental organisations. This represents a wide variety of people with different background, culture and missions. For that reason the result of all discussions is a COMPROMISE. In the discussions with so many people, reality, facts and suitable solutions are always losing the battle against short term political gains, lack of knowledge and "cold-water fear". Sometimes this atmosphere and working procedures result in unrealistic rules and regulations.

Examples of IMD "bloopers:"
- The equations in the damage stability rules for passenger ships are violating proven mathematical law's.
- MARPOL tries to reduce the oil spills by ships. Ships are restricted in pumping overboard oil; countries have to provide oil reception facilities. Countries that insisted most on environmental success have neglected to build reception facilities since. Twenty years after the enforcement to equip tankers with ballast monitoring sensors, it is not possible to fulfil the prescribed technical requirements.
- Herald of Free Enterprise For many years this vessel pops up in IMD discussions. Political pressure forced the Department of Transport to submit a lengthy list of proposals about lights, camera's, inclining tests, etc., irrespective the fact that not the hardware but the procedures caused the tragic loss of this vessel. Internationally the IMD delegations are too polite to reject everything.
- The many years of discussions about dangerous goods have not resulted in a one-to-one relation between a substance and an UN-number. Thirty years after the global introduction of computers, dangerous goods administration is still a lot of manual work, blood, sweat and tears.
- The Tonnage Convention The Tonnage Measurement Convention prescribes many complex rules and regulations in order to establish a figure to describe the size of a vessel, while simple parameters such as length, depth, draught and beam are at hand.

The above mentioned (questionable) rules and regulations are the basis of the safety of a vessel.
Owners versus shipyards

Shipyards have to operate in a very competitive market. They optimize their designs to minimum production costs. Shipyards never sail with ships and consequently do not receive operational feedback. Although shipyards do their best, they have no access to the right information.

Shipowners have their own people sailing on vessels. Every vessel has a safety committee. When safety is at stake the relevant information is immediately available at the head office (design department). In order to assure the safety of the employees in operational conditions shipowners will add safety equipment and/or change shipyard designs.

Some examples of added safety features in "owners" ships:
- Additional fire detection in spaces where it is not mandatory.
- No oil lines over engines.
- No fuel tanks and fuel drains in the vicinity of exhaust gas lines
- Special care for coupling method in fuel lines in order to prevent leakage.
- An extensive system to monitor engine room- and deck systems. Alarms are given when an parameter is out of range.
- Platforms to be made with closed anti-slip plating.
- Reduction of steps in decks and platforms.
- More navigation equipment than prescribed.
- Ergonomic design of wheelhouse, so all relevant information is readily available.
- No electric cables above engines.
- No steep stairs in engine room, accommodation and on deck.
- No control rooms over engines.
- Thicker shell plating at vulnerable positions (anchor, keelplating, rudderhorn, etc.).

Shipowners improve the safety of their ships by changing yard standards and by adding equipment.

The Nedlloyd "Ultimate Container Carrier"

When designing a vessel of a novel kind, it becomes apparent that some old fashioned rules and regulations cannot be incorporated in the design. Nedlloyd faced this situation when designing the Ultimate Container Carrier (U.C.C.).

The UCC design had problems with:
- Watertight integrity as prescribed in the International Load Line Convention, because the calculation of the freeboard (1890, amended) is based on the existence of a watertight upperdeck.
The UCC has no watertight upperdeck, we had to find an alternative.
- Fire fighting regulations, which stipulate that cargo holds should be equipped with a gas type fire fighting system, or equivalent. As gas can be blown away from an open cargo hold, we had to find an equivalent.
- Dangerous goods regulations, which make a distinctive difference between enclosed spaces and other spaces. On UCC type vessels there are not so many enclosed spaces. In order to be flexible in the carriage of dangerous goods we had to find solutions.

Fortunately The Netherlands Shipping Inspectorate (N.S.I.) is a pragmatic and knowledgeable organisation. Nedlloyd and NSI together found sound and safe solutions.

Watertight integrity

In order to ascertain the safety of a vessel without a closed upperdeck, seakeeping model tests in extreme weather conditions are required. The importance of the model tests is to assess the freeboard at maximum draught.

An extensive model test program was established based on experience gained in the past during the implementation of so called dock-ships. This means that reality prevailed old fashioned calculating methods.

Model tests have been carried out in long crested, irregular waves. The Pierson-Moskowitz wave spectrum generated for the purpose of these experiments had a significant wave height of approx. 8.5 m and an average wave period of approx. 10.5 s, which corresponds to sea state 11, according to the scale of Beaufort.

The model experiments were carried out with various headings and different ship speeds, including dead ship condition.

The loading condition during the tests corresponded the maximum intended draught. The most unfavorable hold in terms of shipping of water was simulated to be empty, which means that no protection was provided by protruding containers.

In addition to the usual parameters (ship motions, ship speed, relative motions, rudder angles, etc.) the volume of water entering the holds was measured for each experiment. Moreover the accelerations were measured as a backup of the strength calculations of the cellguides.

NSI has not stipulated the maximum quantity of shipped water, but a very small percentage of the volume of displacement (less than one percent) is considered as acceptable. Nedlloyd was more stringent than the Administration. The Administration’s prime objective is to cater for the safety of the crew and vessel, both allowed to become wet. Considerations based on "care for cargo" have led to an additional requirement where the maximum quantity of shipped water should be less than the quantity of water as a result of a rain shower. This ensures that the maximum "water load" on the cargo does not exceed presently accepted levels.
Both the quantity of water shipped during the model tests and the water coming in the vessel during a tropical rain are taken into account in the determination of the bilge pump capacity.

The pump arrangement is as follows:
1. Two centrifugal bilge/ballast pump units, one of which is placed in a separate space outside the engine room and connected to the emergency switchboard.
2. Each centrifugal pump is capable of pumping either:
   a. The maximum quantity of shipped water, measured during the seakeeping tests with an ample safety margin; or
   b. The quantity of water ingress into the exposed cargo holds owing to a tropical rainfall; whichever is the greater.
3. Additionally, two ejector pumps are installed to serve a fully automatic bilge pump and stripping system. One ejector is placed outside the engine room and driven by emergency power.

The carriage of dangerous goods

On conventional vessels the cargo holds are considered to be an enclosed space. These spaces are separated from the deck by hatch covers. The deck area and the hold area are treated as separate spaces in relation to the carriage of dangerous goods.

The majority of the dangerous goods is carried on deck.

On a UCC-type vessel dangerous goods may leak into the cargo hold. For that reason all containers in and over the cargohold are considered to be loaded in the same compartment. This situation reduces the flexibility to carry containers with dangerous goods.

In order to obtain sufficient flexibility in the carriage of dangerous goods, the cargo holds No. 1 and No. 2 are constructed as conventional holds with hatch covers.

These two cargo holds are especially equipped with appendages to carry all types of dangerous goods except explosives. These holds will be used to carry "special" cargo as well.

Fire detection and fire fighting

The usual ionization type sensors are not suitable in weather exposed areas. A system was chosen whereby air is sucked from each cross-over in the cargo hold. The air is analysed continuously. Smoke in the air will activate the electronic monitoring system and a fire alarm will be given.

The best prevention against a blaze in a container is the container itself. The steel container box will damp down a fire by its protection against incoming oxygen. However, the international rules do not count for containerized cargo. The authorities have never given any credit to this built-in fire protection "device" on container vessels.
The closed cargo holds of a conventional container vessel are normally protected with a gas type (CO₂) fire extinguishing system. The deletion of the hatch covers makes this method of extinguishing system very unreliable, as CO₂ may be blown out of the holds by the wind.

On the UCC-type vessels a water spray system was selected to protect both the vessel and the cargo. Each container bay can be isolated by a water curtain from the rest of the cargo and from the vessel's structure. This system was approved after several nozzle arrangements and nozzle types were tested in full scale on board the "Nedlloyd Dejima".

The engine room and the conventional holds are protected by a CO₂ extinguishing system.

Conclusions

The Ultimate Container Carrier, a typical example of an owner's design, was carefully designed. The vessel could not fulfill the requirements of the International Loadline Convention. Practical and reliable solutions have been found to solve this problem. The Netherlands Maritime Authorities have anticipated very well during the design process in order to arrive at a sound and safe vessel.
A high level of safety onboard chemical tankers is necessary to ensure the best adequate protection for the cargo, the crew and the environment.

Given the subject of this conference and the fact that environmental accidents, even the smallest accident, get and have the full attention of the media, I will restrict myself to the safety related to the environment and ask the question: "how safe are chemical tankers for the environment?".

This environment-related safety is a complicated subject and is in fact a chain of single units acting together to achieve the common objective.

The number of units differ widely from ship to ship and from company to company and perhaps also from flag to flag.

Our company, Gebr. Broere B.V., operates 15 seagoing chemical tankers and 15 inland chemical tankers, all ships sailing under Dutch flag. It is obvious to answer the question "how safe are chemical tankers" I will base myself on experiences with our own ships.

Of course we are convinced that we have safe ships in our fleet, but what is a safe ship in general:

A ship is safe and efficient if being properly:

* designed
* built
* manned
* operated
* maintained
* surveyed

Especially for the environment we have to amplify these "units".

Design
Apart from the normal requirements which every ship has to meet, for example intact stability, the environment is especially protected by the type of the chemical tanker and the damage stability requirements. In the International Code for the Construction and equipment of ships carrying dangerous chemicals in bulk (IBC code) for each product the type of ship is prescribed.

I presume we all know that there are 3 types of chemical tankers, namely type I, II and III (fig. 1).
Type II is the most common one in our fleet and almost for all chemical tankers. This type is also known as the "double hull" tanker.

Ever since the introduction of the IBC code, in the early seventies, the double hull has been recognized by all parties as the answer to reducing pollution in case of accidents with chemical tankers. Of course, there are arguments both for and against double hulls.

On the positive side:

* Most collisions and groundings involving tankers are low energy accidents, which are unlikely to penetrate the inner hull.

* The technology for building double hulls is well known, albeit applied to smaller ships.

* It has, as a design, a proven track record.

On the negative side:

* Increased building costs.

* Increased maintenance and repair costs.

* Reduced cubic capacity

In our company we have a 20 years experience with double hulls and I think we can confirm the above mentioned positive and negative arguments.
Unfortunately in these 20 years, we also had experience with collisions in the cargo area. However, as a bright spot in these dark events the double hull showed its importance and provided environmental protection. In two cases our ships, being anchored, were hit by another (bigger) ship in the cargo area. The collisions took place in heavy fog and they did not breach the cargo tank because of the double hull.

In these two cases it was a matter of a low energy accident, the third collision was clearly a high energy accident when our 2500 tons deadweight double hull tanker was hit by a 50,000 tons deadweight container vessel under an angle of about 30° at rather high speed. Unfortunately our ship did not survive this collision. During the salvage of the ship we could unload the cargo from the forward cargo tanks. Due to the double hull these cargo tanks were not damaged, although the outside hull had been pressed against the longitudinal outside bulkhead of the cargo tank.

During the grounding our ship, with about 800 tons "black frost" on deck, and with an angle of heel about 60° was blown on the sandy beach of Northern Poland. The double bottom was completely destroyed but also in this case we could unload the ship after the salvage operations because the bottom of the cargo tank was undamaged.

The American legislation decided in the wake of the EXXON VALDEZ accident that the double hull for oil tankers was the answer to prevent pollution.

On August 18th, 1990 a completely new piece of legislation, the Oil Pollution Act (OPA) came into effect, with the aim to provide an overall technical and legal response to the problem of marine conservation. This legislation reflects an all-encompassing approach to safety at sea on three levels.

1. Prevention of accidents.
2. Anti-pollution plan.
3. Removal of damage.

It provides a general strengthening of the safety of tankers in three ways.

1. Construction and equipment (double hulls).
2. Operation (crewing standards and rules on drug and alcohol abuse).
3. Navigation (compulsory piloting and towing, maritime traffic control system).

The Act gives provisions for existing tankers after January 1st 1995, all tankers after the year 2000, and newbuildings or those undergoing major conversions (of course all ships operating in American waters).

This is not the end of the story. In a recent paper the US National Research Council stated that "The OPA 90 - should be viewed as only an interim step to reducing oil spills" and has agreed that there are other designs which might offer an equivalent degree of environmental protection. IMO has already recognized that other designs can provide protection equivalent to double hulls.

There are two methods of minimizing pollution in the event of an accident. The first is to prevent the cargo tanks being breached, as double hulls are designed to, the second is to minimize the oil escaping from the tanks once the breach has occurred, the latter almost invariably involves the use of hydrostatic balance.
The IMO has set up a sub-committee under the auspices of the Marine Pollution Committee (MEPC) to study the questions raised.

A number of alternative designs has been proposed already. The mid-deck tanker of Mitsubishi (fig. 2) has gained preliminary acceptance from the IMO as an equivalent to double hulls. But also other designs are interesting such as the mid-deck tankers with rescue tanks, a design of Phillipe Embiricos (fig. 3). The Polis design (see fig. 4) and the Polmis design developed by George Paraskevopoulos (fig. 5). All designs promote hydrostatic balance as the answer to reducing pollution.

![fig. 2 The mid-deck design of Mitsubishi](image)

![fig. 3 The mid-decker with rescue tanks](image)

![fig. 4 The Polis design](image)

![fig. 5 The Polmis design](image)
During the thirty-second session in March 1992, the MEPC decided on the new Regulations 13F "design of new tankers" and 13G "treatment of existing tankers". These new regulations will come into force on the 6th of July 1993.

In these regulations also smaller oil tankers are mentioned (between 600 and 5000 DWT) and provisions were also made for alternative designs.

In the future all these new regulations, etc. will also have their influence on chemical tankers, even on the smaller ones. For example in our fleet the recently built ships have already a certificate for an "oil- and chemical tanker" in order to transport the oil products mentioned in appendix I of ANNEX I. If we and other owners want to transport these products in the future, it is obvious that we have to follow these new rules for oil tankers in and after 1993. And perhaps at that time, even alternative designs have been developed for smaller chemical and oil tankers.

It was already mentioned that next to the design the environment is also protected by the damage stability requirements as mentioned in the IBC code, chapter 2.5 "damage assumptions" and 2.9. "survival requirements".

Although these requirements are very important in the design stage, especially for smaller ships it is a difficult demand to meet, I will restrict myself hereby saying that every chemical tanker has to comply with these rules, with or without a loading manual, because if not the national authorities do not hand out the Certificate of Fitness and without this certificate it is impossible to sail.

Building
A properly built and constructed ship is of great importance for the safety.

This was recently emphasized with a great number of bulkcarrier casualties experiencing extensive structural failure. Twelve of these vessels sank during 1990.

The Advanced Studies and Rule Development Group of Lloyd's Register and similar groups of other classification societies have investigated the causes of these incidents, as far as evidence was available.

The results of these investigations have been published and without doubt also during this conference we will hear something about the results and the theories as to why these casualties are occurring.

What is certain, however, is that these vessels were not structurally capable of safely fulfilling the task for which they were intended,

- whether because their designs have not ensured sufficient structural strength under all possible loading conditions,
- whether the ship had been loaded in a wrong order,
- whether the ship had not been properly maintained
- or the captain was steaming too fast in heavy weather.

Any of these factors may have contributed to some greater or lesser extent.

There are valuable lessons to be learned from these investigations, valuable also for the safety of chemical tankers.

Especially the longitudinal strength is important and has to be calculated in the design stage for all possible loading conditions. Norske Veritas advises to include these calculations in the contract specifications of newbuildings.
Also other recommendations have been made by the classification societies, but let us not forget that these societies are not responsible.
They are not accountable to anyone - neither the shipowner nor the insurers or national authorities, who rely on their ship monitoring procedures.

The shipowner is responsible, he has to supply the necessary money for maintenance and take the ship out of operations for inspections and/or survey. Of course the shipowner wants to lengthening the time between two surveys as much as possible. Therefore intermediate inspections by the crew or inspectors of the Technical Department of the shipping company can help to discover excessive corrosion rates, cracking or structural damage. All in close cooperation with and the support of the classification societies.

Manning
Adequate manning by qualified and competent crew is a key element in ship safety.
However, in practice there are some difficulties with this statement. First the demand for qualified maritime officers to work on board merchant ships is considerably greater than qualified personnel seeking employment at sea.
This situation is the complete reverse of the position as it was 8 or 10 years ago when substantial unemployment amongst merchant officers turned young people away from the profession.

According to the Royal Netherlands shipowners' Association (KNRV) one of the main causes for the ship manning and management problems facing shipowners is the continuous run of drastic changes experienced by shipping during the past century.

On board of today's ships which are packed with sophisticated state of the art electronic systems, many of the traditional positions have ceased to exist and some have been drastically stripped from their substance and glamour with the result that they lost much of their earlier fascination and attraction for young people seeking a career different from traditional jobs.

It is feared not only by the KNRV but also by the Short Sea Association of Shipowners (VNRK) that this will lead to a very serious shortage of higher educated and trained maritime officers.

There are some answers to these difficulties. First the new maritime officer or the MAROF, according to the KNRV, a person who not only knows his navigation and is familiar with ship propulsion but who also knows about automation, modern management and telecommunication.
The second answer that many shipowners are reducing the size of their crews, although this is for another reason, namely to save money.

We stated already that a well maintained ship is one of the safety units, good maintenance needs also practically trained people, but during the education on the secondary and higher institutes for nautical education there is hardly any time left for practical training, which means that professional skill is under pressure. Also the standard of the existing crew can be a problem when nothing is done to raise this standard in order to meet the developments in the technical field etc.
That a competent and well trained crew is very important for the safety is emphasized by the recently published study of claims experienced by United Kingdom Mutual Steam Ship Assurance Association, the largest in this field.

They found that human error is an identifiable cause of 58% of the claims but the true figure is probably higher as casualties caused by equipment failure arising from human errors would be categorized as having mechanical causes.

It is a very interesting report, too long for a review in this paper but the recommendations, to reduce this human factor in the future, are important enough to mention:

* Cargo knowledge, measures should be taken that ship officers are familiar with cargo characters.
* Safety audits and programmes that reward accident free operations with a bonus should be considered.
* Adequate manning for the trade in which a ship is engaged in is necessary if flag state regulations permit lower level.
* Better training and motivation of both seafarers and shore personnel is of prime importance.
* There should be company operating manuals rather than random collection of circulars.
* Officers and crew should spend longer periods on familiarization before new ships are brought into service.
* All on board a ship should be able to use a common language.

To put it briefly, a lot has to be done to reduce the human factor in many accidents, not only for shipping in general but also for the owner of chemical tankers due to the high risk of polluting the environment when a casualty occurs.

### Inland tankers

It is interesting to make a side-step to the inland barges.

At the end of last year the Department of Transport of Germany published a report of Mr Jungmann about the safety of inland shipping.

He investigated the shipping accidents on the river Rhine over the last 20 years and came up with the following accident causes:

- Human error: 64%
- Technical causes: 10%
- Technical problems with traffic routes and constructions: 6%
- Weather conditions: 4%
- Cargo problems during loading or unloading: 4%
- Not identified: 12%

Given the high factor of human error the recommendations for the crew of the seagoing ships can be the same for the crews of the inland tankers.
It will be obvious that the inland chemical tankers have many similarities with the seagoing chemical tankers.

The double hull ship has been introduced a couple of years ago (fig. 6) together with the corresponding damage stability requirements.

Fortunately we do not have a casualty record of the double hull inland tankers but still there are some doubts about the calculated damage after a collision.

In order to check the applied computer simulators full scale ship collision tests were held in December 1991.

In Session 8B of this conference the results of these tests will be announced.

The General Rhine Commission (CCNR), is now drafting a revision of the ADNR (The Rhine regulations for the transport of dangerous cargoes). The ADNR revision will bring ADNR in line with the rules of ADR (dangerous goods by road) and RID (dangerous goods by rail), while CCNR also aims to harmonize its requirements with those of IMO, which has strict codes for the sea transportation of chemicals, both in bulk and in packaged form.

The new regulations will become product dependent instead of shiptype dependent. They are designed to improve the safe handling of chemical cargoes and will also widen the range of chemical cargoes which inland vessels are permitted to carry.

fig. 6 ADNR type IIA Tanker
Conclusion
Summarizing we can say that a well-designed, well built, properly manned and sufficiently maintained chemical tanker is safe for the environment but that the responsibility to maintain this safety standard is not only a task for the ship and her crew. The best way to express what I mean is to quote the words of Mr William A. O'Neill, Secretary-General of IMO in his annual message for World Maritime Day. Although he spoke in particular about the safety of passenger vessels I think his lesson is applicable to all types of ships.

The Secretary-General emphasized that:

"No single unit in the safety chain can act alone but, instead, all must work in concert to achieve the common objective. Shipbuilders, classification societies, shipowners, shipmanagers, charterers, insurers, seafarers, unions, government administrations and IMO must do all their part to bring about safer shipping".

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Safety integrated vessel design, the Beamer 2000

J.A. Stoop

Summary

This contribution describes significant developments in society and in the technology in the Dutch fishing industry which emphasize the need for major changes in the design of fishing vessels. By deploying a scientific approach, the safety integrated design method KINDUNOS, it is possible to integrate safety in an early phase in the design process. Major improvements are possible in the conceptual phase of the design. A systematic approach is described in which safety is an explicit aspect in the design procedure, weighed against other design criteria. The Beamer 2000, as a result of this design study, takes into account the safety, working conditions and the work load on the bridge, the fishing deck, the processing and storage of the catch, the engine room and noise and vibration in the accommodation. The potential for further improvements are indicated. The design is evaluated with respect to residual risks and the necessity of additional risk reduction strategies of a non-technical nature. Finally, the possibilities are discussed to apply the method more in general to the design of other types of vessels.

Conference on Marine safety and Environment, June 1-5, 1992, Delft.

1. Ad hoc versus prevention

In the last three decades sea fishing in the Netherlands has developed from a craft to a modern industry. In this industry micro-electronics and information technology are widely applied for navigation and communication, fish detection and engine monitoring. Although technical developments and market demands have increasingly mechanized and controlled the process, the processing and storage of the catch on board and the selling of the catch at the auction are still organized traditionally. For many years the Dutch fishing industry has constructed vessels by adopting parent vessels and semi-serial building has been more the rule than the exception. Beam trawling, the most important Dutch fishing technique, is undergoing significant changes. After a period of growth and mechanization, the emphasis has shifted from scaling up and increased efficiency to improvement of the quality and the reduction of the costs gained by means of catch quota restrictions and fishing day limitations. The traditional practices of fish processing are being re-examined in the light of quality assurance standards for chilled flat fish. The processing of the catch both on board and ashore have become related by quality assurance and logistic requirements. Additionally, due to oncoming European guidelines, demands are put on better safety and working conditions for the skipper and his crew and on a better marine environment.

The increased complexity, scaling up and interrelation of the various aspects requires a new approach. By deploying a scientific approach - the method KINDUNOS, which means 'hazard' in Greek - it is possible to integrate safety at an early phase of the design process. Major improvements are possible in the conceptual phase of the design. Instead of an ad-hoc approach, such a safety integrated design should result in a durable safe fishing process.
2. A safety integrated design process

2.1 A multi-disciplinary approach
A designer of fishing vessels is confronted with these developments because he has to fulfill the demands of his assignment within the constraints of the new regulations. In practice however, in the analysis of the safety problem, a maritime designer does not have the required accident data, noise and acceleration level data at his disposal; neither does he have the time and skills to analyze the accidents or to transform the results of the analysis into design specifications. During the evaluation of the design, he has limited possibilities to foresee future use or to formulate strategies of a non-technical nature which have to deal with residual risks and side effects. Therefore, the designer has to cooperate with safety experts and maritime researchers within a design team. The goal of this cooperation is to elaborate generically formulated 'soft' safety objectives into 'hard' specifically formulated design requirements which can be integrated into the overall Programme of Requirements for the designer and which may serve as the basis for the evaluation of the design (Stoop and Veenstra, 1992. 2).

2.2 Problem development
A generic description of safety on board does not lead to successful design intervention. For a design intervention, safety problems must to be broken up into manageable sub-problems which contain satisfactory explanations of cause and effect relationships. The basis for the safety analysis in the fishing industry was found in the Verdicts of the Dutch Admiralty Court. In the Verdicts, fishing vessels were overrepresented with respect to to collisions and severe occupational accidents, especially those in which beam trawlers were involved. Although the reports of the Shipping Inspectorate described the accidents in detail, additional information had to be collected in order to supply the research team with satisfactory explanations of the accidents and to formulate generally valid patterns beyond the level of individual case histories. Additional accident material was found in the data of the Radio Medical Services of the Red Cross, the Labour Inspectorate and the Social Fund for the Partnership Fisheries. Observations on board and analysis of the normative tasks in the various work stations supplied the team with a good insight into the way these tasks were performed. Underlying causes of accidents and work load were revealed by further research in several fields on specific topics such as the application of human error theories, noise and acceleration level measurements and estimates of human energy consumption. The analysis led to the definition of the following sub-problem areas in which different aspects and dominant problems occurred.

- on the bridge, dominant problems were encountered with the mental load of the operator, the interfacing of the electronic equipment, the vision lines to and communication with the decks and the surrounding traffic and the layout of the bridge and the steering console (Buijs and Van der Sluis, 1991)
- on the fishing deck, the physical load of the crew during the handling of the nets and the cod-end was dominant, together with the risk of severe accidents during handling of the gear at the fish processing station and during storage in the fish hold, much manual handling and lifting caused an exceptional heavy physical load, aggravated by high acceleration levels and climatic conditions (Hoefnagels et al, 1990)
- in the engine room the layout of the main and auxiliaries systems are not matching quite well with regard to energy consumption, remote controlling, marine environment and maintenance.
Before a design team may proceed with the design, two points have to be clear with regard to the setting of priorities and the scope of the design improvements. Firstly, the causes of accidents can be beyond the scope of the redesign of the workstation where they occur. Problem areas are interrelated. For example, the phenomenon of 'falling' on the fishing deck must be divided into three types, because of their different underlying causes. Falling can occur during the handling of heavy gear, where the crew has to operate the nets, beams and chains and can be struck by the hoisting equipment. Falling can be caused by violent movements of the vessel, knocking the crew off their feet. Falling can be the result of being hit by heavy stones, debris or other heavy material caught in the nets and brought on deck during the hauling of the cod-end. Each of these causes can have different solutions, varying from gear redesign, or hull modification, to containers on deck for undesirable by-catch storage. If such a solution is beyond the scope of the design assignment, hazards will remain and residual risks will have to be dealt with accordingly.

Secondly, the analysis will probably reveal a need for further research into several different fields, without which the quality of the problem description could be inadequate, thereby causing uncertainty about the adequacy of the design solutions. The analysis of safety on board of beam trawlers, indicated the necessity for research into:

- the tasks of the man on the bridge with respect to the modelling of human error, the need for an architecture in the presentation of information, including engine room control and alarming and for an adequate programme for simulation and training
- Electro Magnetic Interference of the equipment, especially in the light of future trends in automation and the restricted space for the equipment available on the bridge
- the dynamic modelling of the gear behaviour in interaction with the vessel, especially under heavy sea-going conditions (Van der Nat et al, 1992)
- more detailed measurements of acceleration and noise levels, especially with respect to noise transfer from the stern and propeller to the accommodation area (Veenstra, 1988).

3. Analysis results

3.1 A systems model

The analysis makes it possible to derive a systems model of the beam trawler, representing the safety problems on board. Such a model enables the design team to describe the sub-problems in relation to each other and to the vessel as a whole. (see figure 1)

The model clarifies the boundaries which are chosen if sub-problem areas are elaborated. Problems which are not selected for elaboration or have their underlying causes in other areas, will cause residual risks in the selected sub-problem area. During the evaluation these effects must be foreseen and coped with appropriately. Additionally, solutions in one area may have an effect in other areas; eg changing the working deck layout, changes the vision for the skipper on the bridge during his winch operation tasks and will alter the crossing routes for the crew from the accommodation area to the processing work station.
3.2 Safety in the design requirements

The results of the analysis are translated into safety and health requirements for the overall Programme of Requirements, in a step by step procedure:
- the safety and health demands are collated by workstation; i.e. fish deck, bridge, engine room and accommodation
- additional demands with respect to environmental issues and the quality of the fish as a product are elaborated by workstation
- all demands are brought together into a set of requirements, specific to that workstation
- these sets are arranged in a specific to type of vessel set of requirements, suitable for integration into the overall Programme of Requirements.

This overall Programme of Requirements is methodically developed through the various design phases by means of the, with ship designers well known, Design Spiral until a satisfactory result is produced. Safety and working conditions form a new segment in the spiral and are elaborated parallel with the other design requirements.

(see figure 2)

The final result of the problem analysis consists of three items, which are of interest for the design team members:
- a problem description in which safety case studies and research findings are transformed into a complex model of the fishing vessel. This model facilitates a systematic and coherent development of the problem in which future effects are foreseeable
- an integral Programme of Requirements in which safety and health issues are weighed against other requirements
- a research programme in which greater expertise of the researchers is developed, giving a better insight into the problems and aiming at better assessment and control.
4. From Analysis to Synthesis

4.1 Principal decision points

In the transition from analysis to synthesis some crucial steps are present in the design spiral, in which safety is a principal issue. The safety integrated design method KINDUNOS contains 5 principal decisions with respect to safety (Stoop, 1990). In the conceptual phase of the design process, substantial improvements are possible. The first decisions define the attainable levels of safety for the later phases which only can be influenced with great cost and additional measures. These principal decisions run parallel with the design spiral and should be processed in a time sequence.

They focus respectively on:

- the formulation of the design requirements. Safety aspects should be explicitly present in the objectives and should specify the target group, the safety requirements and the hazards to be dealt with. Until recently, the safety and health of the skipper and his crew, the so-called 'Arbo law' working conditions were not explicitly present in the design requirements of a fishing vessel and therefore were not elaborated upon during the design.
- the hazards inherent in the choice of a technology, energy supply and the overall layout applied to a design. The selection of a mechanically driven winch and of warps for hoisting heavy loads, introduces different hazards than those for a hydraulic or electric crane. The position of the processing work station under the foredeck instead of under the bridge in the middle of the vessel introduces a different magnitude of acceleration levels in the processing workstation and also creates different transport routes around the vessel for the crew.
- the consequences of the decisions in the conceptual phases. Hazards introduced in the early phases should be dealt with during the detailing of the design. Once the hazards are introduced, they should be mitigated or compensated for by effective risk-reducing strategies. If warps are applied, they should not run over a working deck at head height but should be confined in warp runs or should be operated with self-tensioning winches equipped with emergency stops.
- interrelation between all previous design decisions may cause unforeseen effects for other work stations on board. A redesign of the fishing deck may cause vision problems for the skipper on the bridge during winch operation. Alteration of the skippers vision lines in order to deal with this problem, must take
into account his navigation and watch keeping tasks as well as his ability to operate and monitor the equipment on the bridge. Residual risks which are not dealt with in the design should be managed with measures of a non-technical nature once the design is finished. Additional measures may be necessary with respect to the certification of equipment, the training of the crew, legislation with respect to working time restrictions and the number of crew members or organization of the work on board.

4.2 The solution matrix scheme

The transition from analysis to synthesis is made by means of a solution matrix scheme. This matrix scheme is developed as an instrument in order to structure and grade the various solutions by their nature and scope. On a horizontal axis, the solutions are classified into their relevance for the workstations, the design of the vessel and the organization of the labour. On a vertical axis the solutions are graded by the impact which they have on the vessel, varying from minor alterations within the existing vessel layout, a partial adjustment of the layout, up to the redesign of the vessel layout.

<table>
<thead>
<tr>
<th>concepts</th>
<th>workstation</th>
<th>vessel design</th>
<th>labour organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>within existing layout</td>
<td>• warp containment &lt;br&gt; • safe working zones &lt;br&gt; • control of objects &lt;br&gt; • relocation of hoisting and control stations</td>
<td>• communication bridge-fishing deck &lt;br&gt; • vision lines to crew on deck &lt;br&gt; • noise abatement &lt;br&gt; • reduction of vessel movements</td>
<td>• education licenses &lt;br&gt; • protective clothing &lt;br&gt; • emergency brakes on winches &lt;br&gt; • certification of hoisting equipment and gear components</td>
</tr>
<tr>
<td>partial adjustment</td>
<td>• cod-end containment &lt;br&gt; • replacement gipsy heads by drums</td>
<td>• noise reduction at the source &lt;br&gt; • hull optimization &lt;br&gt; • exchange winch and processing station &lt;br&gt; • elevation of bridges</td>
<td>• increase crew size &lt;br&gt; • mechanization and automation increase &lt;br&gt; • restricted working times</td>
</tr>
<tr>
<td>new concept</td>
<td>• mast backwards &lt;br&gt; • fishing pits to the side &lt;br&gt; • hydraulic cranes for multifunctional purposes &lt;br&gt; • quality control fish processing</td>
<td>• implementation of all noise abating measures &lt;br&gt; • processing workstation amid ships &lt;br&gt; • automated storage in the fish hold</td>
<td>• no waste overboard &lt;br&gt; • watch and leave similar to merchant marine &lt;br&gt; • optimized mechanization and automation</td>
</tr>
</tbody>
</table>

Figure 3: Solution matrix scheme fishing deck
This matrix scheme permits the design team to compose 'best technical solutions' for the overall vessel design as well as for local work station design. These 'best solutions' deal with several hazards at a time and eliminate or mitigate the hazards and not merely influence their effects. They often consist of multifunctional tools, such as hydraulic cranes on the fishing deck, or introduce new technical solutions, such as integrated visual displays on the bridge (De Vries, 1990).

The selection of solutions for further elaboration is done by a cost-benefit estimate of the different solutions. Several packages of solutions are produced, graded by their cost, so that each skipper-owner can select the package appropriate to his financial resources and personal preferences; quality of work, quality of fish and quality of marine environment.

The residual risks are estimated by consulting several experts. The acceptability of the residual risks is determined and the non-technical measures required to cope with these risks are estimated (Stoop and Veenstra, 1992).

To reach a durable solution in practice, all stakeholders must be involved in a further development of the solutions. The solutions must be discussed with shipyards, skipper-owners, governmental experts, research institutes and branch organisations through the medium of articles, talks, discussion sessions and of contacts during trade exhibitions.

The possibilities of developing implementation strategies in several problem areas may vary:
- noise reduction was possible due to a governmental grant for implementation of several noise reduction packages on demonstration vessels
- improvement of the safety and working conditions on the fishing deck and the processing and storage of the catch was made possible by the installation of a Safety Working Group, which formulates guidelines for the design and construction of fishing vessels. This group included the Labour Inspectorate, Shipping Inspectorate, shipyards, branch organisation and the research institute,
- improvement of the flatfish processing due to EC funding to optimize the fish routing procedure led to cooperative international research
- cooperation with a manufacturer of electronic equipment resulted in a redesign of the bridge console. A full scale model of a Bridge 2000 was demonstrated on several trade exhibitions and can be used to perform simulation experiments
- cooperation with a diesel engine manufacturer was possible to introduce the 'green and low-noise' diesel engine in the fisheries.

The solutions can be separated into two main classes. The first class consists of improvements at work station level on existing vessels, without costly alteration to the vessel layout. The second class comprises solutions which are only profitable for new build vessels because they change the overall layout of the vessel. The 'best technical solutions' are most profitable on new build vessels, due to the increase of safety levels with minimum costs. The implementation of the 'best technical solutions' combined with a change in beamer layout, resulted in a new beamer; the Beamer 2000 (Stoop, 1992).

This Beamer 2000 has the following overall characteristics:
- application of noise-reducing packages resulting in a better communication with crew and maritime traffic, less stress and hearing loss, less fatigue and more attention to the quality of the catch and the environment
- exchange of the winch under the bridge with the processing workstation under the foredeck eliminates warps running over the fishing deck, reduces the physical workload due to acceleration levels during processing, the fatigue of the crew and eliminates the crossing of the hazardous fishing deck when moving from accommodation to the processing workstation.
- elevation of the bridge and alteration of the layout gives the skipper a better view of the decks and the maritime traffic, reduces the mental load of the man on the bridge and reduces the possibility of collisions
- a better engine room layout regarding low energy consumption, an environmental impact and easier maintenance (see figure 4).

Figure 4

5. The conceptual level

Although the beamer 2000 improves considerably the safety level on board fishing vessels, the overall concept of the present beamer includes a number of shortcomings which can only be eliminated by the development of a different vessel concept. The application of a morphological chart demonstrates the variety of concepts for fishing vessels. (see figure 5)

Different concepts can be elaborated and the requirements for an optimized fishing process can be weighed against each other. Major modifications of the present beamers are possible with respect to the overall layout of the vessels. A stern beam trawler layout has advantages compared to the present beamers with respect to the separation of noise sources and accommodation, better vision lines, processing and gear handling amidships. Such a vessel already exists and could serve as a parent vessel for a Beamer 2001 configuration. In such a Beamer 2001 application of new technologies is possible in order to cope with the logistic and quality assurance requirements by the introduction of containers and teellauction (Stoop and Veenstra, 1992.1). Fishing techniques could also change by the application of such techniques as electric flatfish stimulation instead of tickler chains. A beamer 2001 concept could serve to promote innovation in the Dutch fishing industry.
6. Evaluation

The safety integrated design method KINDUNOS, structures safety problems, defines procedures and decision points in a time sequence and improves the designer's ability to foresee future use. The method is not restricted to fishing vessels but can easily be extended to the design of other vessels and can be applied to other projects, such as the Channel Tunnel (Eisner and Stoop, 1992). The presentation of a Beamer 2000 concept served already as an incentive in the discussion about safety and working conditions and led to technical improvements on the vessels (Veenstra, 1990).

Besides, all Dutch beamer building shipyards are working out the final specifications and have contract negotiations for actual building. Several skipper-owners and shipyards have considered innovations in connection with noise reduction, the positioning of the winch, the height and layout of the bridge and the application of hydraulic cranes. The analysis of safety and working conditions on the fishing deck indicated its predictive potential. Unfortunately, during the last 2 years, several serious accidents occurred during gear handling, as foreseen in the analysis, and led to verdicts of the Admiralty Court (Raad voor de Scheepvaart, 1990-92).

From 1987 on, a remarkable decrease in collisions with fishing vessels occurred. This decrease, with a magnitude of about 5, is not the result of the redesign of the bridge or the equipment. Such redesigns have still to be implemented in the near future. The decrease is the result of the introduction in 1987 of the Sea days Directive by the Dutch government; a limitation of the days the fishermen are allowed to be at sea. As a result of this directive, it is no longer profitable to go out during aggravated circumstances. As a result, risk taking behaviour by the skipper is no longer profitable and the number of collisions is subsequently lower.

Although efforts on redesign may be promising, there is always a higher order in the system which is likely to influence safety levels far more drastically than any lower order.
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Hydromechanics aspects of marine safety
W. Beukelman

ABSTRACT

From all aspects of marine safety the hydromechanic issue is an important one. The criteria mostly considered and reviewed here, are those related to the still water condition such as transverse intact and damage stability, load lines and manoeuvring qualities. For all these topics criteria already exist or are under development. Special attention is focused at the manoeuvring aspects of fast modern ships in certain environmental conditions such as ferry-boats in restricted water. Another important issue considered here is the behaviour in a seaway especially for high speed advanced ships in high waves. Chaotic behaviour of the transverse stability in ultimate non-linear wave conditions appears to play an increasingly important role. Improved criteria concerning relative motions, accelerations, shipping and slamming should be developed. In this respect accurate and reliable calculation methods, together with aimed experiments and a probabilistic approach, are required to establish these criteria for future safety in marine transport.

INTRODUCTION

Up to now the majority of the considerations related to ship safety is devoted to the still water condition with special emphasis on stability for the up-right situation against capsizing. Another important criterium for the safety of ships is the determination of the load lines or the free board to achieve a certain amount of reserve buoyancy. A good historical review and state of the art about these subjects is presented by Kobilinski (1991)[1]. For both above mentioned criteria general international conferences introduced recommendations and/or requirements [3,4,5,7,10,14].

One more important aspect with respect to damage stability is the required sub-division in a certain number of compartments by watertight bulkheads. With the increase of forward speed, criteria for manoeuvring will be more and more urgent especially related to the ship's condition i.e. trim and sinkage as well as related to the operation in shallow water. Formulation of manoeuvring criteria for designers by the IMO (International Maritime Organization) appears to be a difficult matter.
It might be clear that for considerations about ship safety the dynamic behaviour of a ship in a seaway should be taken into account. At first related to ultimate situations with respect to the safety of crew and passengers but secondly also in view of operational conditions to prevent too much degradation of the performance of persons on board (sea-sickness) and danger for damage of cargo and local ship areas.

For ultimate conditions knowledge about non-linear behaviour is required to simulate possible chaotic situations and to improve the probabilistic approach in finding more reliable criteria.

In the near future given the growing interest in fast advanced ship types such as catamarans, hydrofoils etc., it may be expected that control foils are needed to maintain a safe stable condition in still water and waves for both horizontal and vertical motions. Safety requirements for these high speed craft hardly exist at present, but should be developed.

STILL WATER CONDITION

Intact stability

From the beginning intact stability in still water has been an important issue with respect to safety against capsizing. At the end of the nineteenth century the first attempts were made to evaluate a safe minimum stability. In this respect Rahola (1939)[2] should be mentioned who proposed a set of stability criteria which after the second World War were used in some countries as recommendations. The different International Conferences on Safety of Life at Sea (SOLAS) (1948, 1960) did not present requirements concerning stability criteria.

The 1960 SOLAS Conference recommended the International Maritime Organization (IMO) to study intact stability of ships in order to establish minimum criteria [3]. After collection of data on stability of ships, which either capsized or operated safely, the IMO proposed stability criteria for passenger, cargo and fishing vessels. These proposals were accepted as IMO-recommendations [4,5], but only as temporary ones because the statistical analysis was considered to be based on an insufficient number of data as signalized and specified by Bird and Odabassi (1975)[6]. The IMO continued her work with a programme aimed at the development of so-called 'rational criteria'. These criteria should be based on physical analysis of phenomena leading to capsizing. After some years of study by the IMO Sub-committee little progress had been made because the physics of capsizing are a very complicated problem. It became more and more evident that ship motions generated by waves and wind should be taken into consideration too. And so the IMO Sub-committee expecting only results on the very long term
decided to adopt a more pragmatic approach and accepted a short term programme to improve the existing criteria. In this way the weather criterion arose in which, on an approximate basis, the effects of wind and sea were taken into account [7]. Extensive research over the last 20 years including four international Stab(ility) Conferences, delivered a vast increase of knowledge about the physics of capsizing but up to now no reliable 'rational' stability criteria. Nevertheless, as a result of this continued research it has become evident that safety against capsizing should be considered as a system and dependent on several elements such as the ship, cargo, environment and operation as demonstrated in Fig.1 [1]. For this reason the IMO Subcommittee is trying to develop now an overall code of stability for all ship types considering the afore mentioned elements of the system. It remains questionable if such a solution may be expected in the foreseeable future. A pragmatic way with as its base the existing rules with differentiation in ship types and elements is perhaps preferable or more likely a system with approval by recognized and authorized institutions or organizations. The historical development is remarkable: starting from the still water condition with static stability as the only element for determining criteria it followed from practice that such an approach is too simple. It appeared that the ship dynamic behaviour due to motions in a seaway should be regarded together with other elements of the system.

**Load lines**
Safety considerations for ships started in the second half of the eighteenth century with requirements related to freeboard. The name of Samuel Plimsoll (1824-1898) is connected to the wellknown freeboard mark which is being used up to the present time. Determination of freeboard was based on the assumption that the ship should possess a certain amount of reserve buoyancy, characterized as the volume between the waterline and the uppermost deck exposed to weather. International requirements with respect to freeboard were presented by the first International Conference on Load Lines in 1930 followed by a second conference in 1966 organized by the IMO. At this conference it became already evident that determination of a required freeboard in a rational way is very difficult because of modern developments in seakeeping and because of the possibility of overruling by the recommendations concerning intact and damage stability.
With respect to seakeeping several papers were published such as from Bakenhus (1964) [8] and Krappinger (1964) [9] showing the possibility to determine freeboard based on the idea of using the probability of deck wetness in a predefined seaway.

The 1966 Conference accepted this method and delegated the execution to the technical committee. The developments during the following 20 years were almost similar to those of stability: the problems appeared to be too complex for a sound physical and rational solution applicable for all ship types. So the technical committee decided to adhere to the old principles with re-adjustments of freeboard tables. The only exception worth mentioning is the determination of minimum freeboard for fishing vessels based on deck wetness in a seaway. Because of easy controllability only the minimum distance from the deepest operating waterline to the lower point of the top of the bulwark or to the edge of the working deck and the minimum bow height are considered.

At first formulae for minimum distance were developed based upon regression analysis of results of probability of shipping water on deck which are assumed to be 5 per cent in fully developed beam seas with significant wave heights of 5.4 and 4.0 meters. Formulae for minimum bow height were also developed based upon regression analysis of calculated results of the probability of bow submerging in head seas with a significant wave height of 11.75 meters. This severe condition was assumed in order to ensure survival of the vessel in heavy weather.

The Sub-Committee on Stability, Load Lines and on Fishing Vessels Safety (SLF) agreed in 1987 that deck wetness and reserve buoyancy studies should be conducted concurrently, using the following criteria for deck wetness. [10]

Sea spectrum - ITTC, 2 parameter
Significant wave height - $H_s = 10, 7, 4$ m
Directions of waves - Head seas only.

These studies should be restricted to monohull ships of all sizes. The ships should be considered for $H_s = 10$ m at zero speed, for $H_s = 7$ m and 4 m at 60% and 90% of full speed respectively. For the static swell up of the bow wave Tasaki’s formula [11] should be used

$$\frac{h_B}{L} = 0.75 \frac{B}{L_E} \frac{F_n}{L_E^2}$$  \hspace{1cm} (1)

in which $h_B = \text{static swell up of the bow wave}$
$L_E = \text{entrance length on the waterplane}$

**Damage stability and sub-division**

Around 1850 compartmentalization of ships using watertight bulkheads was first applied in the UK. as a means to pro-
mote survival of the ship after damage of the hull and water inrush. These first limited requirements were applied to passengerships but did not include rules for residual damage stability. Mostly losses of passengerships accelerated the process of regulation in this respect.

The SOLAS convention of 1929 set international sub-division requirements for passengerships, still excluding regulations for damage stability.

However, it was not until the 1948 SOLAS convention that some residual damage stability requirements were included. The sub-division requirements utilizing floodable length concepts were based on vague assumptions involving several 'factors' intended to take account of ship characteristics in an approximate way.

More and more the need was felt to use another approach for the determination of sub-division. If damage is caused by a number of variable (stochastic) parameters which may be described by a probability density distribution it is possible to handle it with a mathematical model usually called the probabilistic method. Such a method was referred to by Comstock and Robertson (1961) [12] and Wendel (1968) [13]. A Working Group on Sub-division and Damage Stability, set up by the IMO, developed probabilistic sub-division standards for passengerships which were adopted by the IMO-Assembly in 1973 as Resolution A.265 [14] as an alternative to the usual deterministic method based on 'factorial' requirements.

In 1985 it was decided that requirements for watertight sub-division and damage stability of cargo ships also could be based on the probabilistic method. Recently draft requirements for cargo ships (for \( L > 100 \text{ m} \)) have been completed to propose them as SOLAS-amendments in 1992. It is the intention that in the future only the probabilistic method for passenger- and cargo ships will be used and the deterministic method will become obsolete.

To improve safety after some serious casualties (eg. Herald of Free Enterprise in 1987) a series of amendments of SOLAS have been accepted. The most important one (SOLAS '90) is that related to residual damage stability enlarging considerably some parameters (Figure 2) [1]. These regulations are applicable for new ships only which means that existing ships are excluded. There is quite a discussion going on about how to find and apply temporary provisions for existing ships, also with respect to the expected regulations for passenger- and cargo ships based on the probabilistic method. For sub-division and damage stability it may be expected that the same developments will be seen as those for load lines and stability: ie. a necessarily growing emphasis on dynamic conditions for damaged ships. Research in pursuance of recent casualties by Vredeveldt and Journée (1991) [15] shows that dynamic behaviour of a ship due to sudden ingress of water cannot be neglected.
Rapid capsizing is caused by a drastic decrease of static stability properties due to free surfaces, as well as by inertia effects with regard to the rolling motion caused by sudden inrush of water. See Figure 3 [15]. A calculation model was developed to determine this motion for a wing tank crossduct configuration. It should be kept in mind that the probabilistic method is always based on the experience of the past only and should follow new developments if possible, with whatever adjustments become necessary. For this reason it is again recommended for damage stability and sub-division to start with authorization by recognized institutes or organizations making use of experiments and/or calculations taking into account the ship type considered.

MANOEUVRABILITY

Up to now safety with respect to manoeuvrability has mainly been considered in relation to actual collisions. This is not amazing because recent statistics show that 1 vessel in 22 is involved in a collision each year. In 80% of these cases other vessels were involved [16]. However it is not well known how many ships come into difficulties because of bad manoeuvring characteristics or a lack of directional stability. For a long time collision avoidance was considered to be purely a navigation problem, until it was recognized that safety against collision is also strongly dependent on the manoeuvring properties of ships.
Present and proposed regulations

First formal regulations for collision avoidance were issued by Trinity House in London in 1840. These regulations were later included in the first SOLAS-convention in 1930. Now they form a separate COLREG Convention which was accepted in 1972.

The first attempt to introduce some manoeuvrability criteria was made in 1971 as a recommendation from the IMO according to resolution A.209 (VII) about some data on manoeuvring characteristics to be included in the Manoeuvring Booklet on board of ships [17].

A revision of this recommendation [18] followed in 1987 and consisted of three parts:

1. Pilot Card
2. Wheelhouse Poster
3. Manoeuvring Booklet

The Pilot Card should provide the present condition of the ship as information to the pilot.

The Wheelhouse Poster should be permanently displayed in the Wheelhouse and provide information about the manoeuvring characteristics of the ship for easy use. The Manoeuvring Booklet on board should contain comprehensive details of the ships manoeuvring characteristics. These data may be obtained either from model tests or ship trials. The IMO also described how to obtain these characteristics.

It should be clear that these recommendations may be helpful for safe ship handling, but criteria were not established.

Different suggestions to formulate manoeuvrability standards have been proposed starting from Nomoto’s (1966) [19] first order equation:

\[ T \ddot{\psi} + \dot{\psi} = K \delta_r \]  

with \( \psi \) = course angle  
\( \delta_r \) = rudder angle  
\( K, T \) = manoeuvring coefficients

The coefficients \( K, T \) should be derived from manoeuvring tests with existing ships and arranged on basis of ship types. Establishing criteria for ship manoeuvring remains a difficult matter for the IMO. The limit between safe and unsafe is hard to determine even for the deep and shallow water condition.

The problem becomes even more complicated if other important elements are taken into account such as: human behaviour, operation and navigation, wind and waves, ship condition and restricted water.

To catch all these influences in one system appears to be
impossible, although planar motion model experiments and manoeuvring simulation can strongly contribute to a responsible judgment, in particular for individual ships or ships of the same class. Also for this aspect of safety authorization by recognized institutes or organizations is almost inevitable on the long term.

Ship condition and environment
The situation of a ferry-boat leaving or entering the harbour is a rather complicated one to analyse. Many hydromechanic elements are playing an important role such as: trim and sinkage, the load condition (draught and trim), the influence of the bow wave, the effect of the bottom and/or side walls of the channel and the presence of waves. After the disaster with the 'Herald of Free Enterprise' there was a heated discussion about the directional or course stability related to the particular conditions of the ship and environment at that time: with bow trim at high forward speed on restricted waterdepth. Bishop and Price (1988) published a study entitled 'On the dangers of trim by the bow' [20]. They put forward there that 'the vessels loss by hydrostatic instability was preceded by loss of control. She (Herald of Free Enterprise) became directionally unstable at high speed in shallow water while trimmed by the bow'. With the aid of linear equations of motion for the ship motion in the horizontal plane the authors put forward as condition for positive stability of the yawing, swaying and rolling system:

$$\rho g V G M [ Y_v N_r + (mU - Y_r)N_v ] > 0$$ (3)

The first factor should be positive because the metacentric height $GM > 0$. The term between the brackets is the well-known criterium of stability for the coupled yaw and sway motion for which the manoeuvring coefficients $Y_v$, $N_r$, $Y_r$ and $N_v$ only depend on the underwater part of the hull form and consequently also on trim and sinkage; $m$ is the mass and $U$ the forward speed component of the ship. The stability criterion may be written as function of the trim:

$$\gamma = \frac{T_{APP} - T_{PPP}}{T_m}$$ (5)

yielding

$$mU_c(\gamma) = \left[ \frac{Y_v(\gamma)}{N_v(\gamma)} N_r(\gamma) \right] + Y_r(\gamma)$$ (6)

in which $U_c = \text{critical speed with respect to stability.}$
After some suppositions about the stability derivatives and their dependence on $\gamma$, analysis of condition (6), Bishop and Price (1988) came to the conclusion that trim by stern increases the critical speed above which instability appears. In the past, experimental research has been carried out to determine the hydrodynamic coefficients of the manoeuvring equations. Forced oscillation tests by a Planar Motion Mechanism (PMM) with a ship model have been used by Gerritsma (1979) [21] to determine these coefficients and the stability roots $\sigma$ as a function of draught and trim by the stern. These experiments were carried out in deep water for two conditions viz. without rudder and propeller and with rudder and rotating propeller. For the last case a positive directional stability could generally be established. It also appears that the influence of forward speed on the directional stability is small compared to that of the draught variation and the trim. Without rudder and propeller directional instability was always present except for the condition of trim by stern.

The influence of trim on the hydrodynamic derivatives has also been investigated by Inoue et al (1981) as reported in [22]. From these studies it appears that just as Gerritsma's (1979) study [21] showed the lateral drift force increases for trim by stern.

Also research carried out by Beukelman (1989) [23] shows that for trim by the stern the drift force indeed increases but the distribution over the ship’s length is more symmetrical fore and aft resulting in a reduction of the drift force moment. The influence of waterdepth on the hydrodynamic derivatives for manoeuvring has been investigated by Hirano et al (1985) [24] and by Beukelman and Gerritsma (1983) [25].

These investigations showed an increase of the damping coefficients (drift force coefficient) $Y_v$ and the added mass coefficient $Y_v$ with a decrease of the waterdepth. Measurements and strip theory calculations taking into account the influence of restricted waterdepth agree reasonably except for the damping coefficient $Y_v$ in the aft part of the ship. To investigate the influence of waterdepth and trim on the directional stability of a Ro-Ro ferry ship PMM tests have been carried out with a model of the 'Herald of Free Enterprise' at the Ship Hydromechanics Laboratory of Delft University [24]. See Figure 4 [26].

For all conditions considered a negative directional stability (positive root $\sigma$) could be observed especially at high forward speeds. See Figure 5 [26,27].

The influence of variation of waterdepth on the directional stability is generally small. However, the effect of the trim condition is more clear, showing an improvement for the case of trim by stern in deep water as shown in Fig. 5. Restriction of forward speed dependent on the waterdepth is strongly recommended.
Calculation of the directional stability is up to now not possible in a satisfactory way because of the lack of knowledge about viscous influence which is essential to determine the manoeuvring coefficients. Further research is required in this respect.

Stability and Control in waves
In the case of head and bow seas the frequency of encounter with waves causing yawing and swaying motion is rather high and since course or directional stability is usually large, serious difficulties seldom arise.

Quite different might be the situation of a ship traveling in quartering or following seas, especially if the frequencies of wave encounter are low so that large roll and yaw moments may build up.

The definition diagram for a ship operating in regular waves is shown in Figure 6 from [28].
Fig. 6: Definition diagram for a ship operating in regular waves. [28]

The frequency of encounter between ship and wave is:

$$\omega_e = \frac{2\pi}{L_w} \frac{(V_w - V\cos \chi)}{V}$$

where:  
- $$\omega_e$$ = frequency of encounter with component waves  
- $$L_w$$ = length of wave components  
- $$V$$ = ship velocity  
- $$V_w$$ = component wave velocity  
- $$\chi$$ = angle from ship velocity vector to wave direction of advance.

The rolling motion may be introduced by the rudder motion but also by the variation of the metacentre M dependent on the position of the ship in the following or overtaking wave and the frequency of encounter approaching the resonance rolling frequency.

The characteristics of the course control system for such a case are of critical importance. If the wave and ship speed are almost equal a situation may arise with zero frequency of encounter so that the wave crest may be present at the midship section for a long time. The metacentric height GM will be reduced because of this position but also due to for example high forward speed influence in some cases. Such a semi-static situation can potentially lead to capsizing. Another critical phenomenon in astern seas is broaching (turning broadside to the waves). When a ship is positioned as shown in Figure 6 with its stern at a crest and its bow in a trough, the orbital wave velocities induce a destabilizing yaw moment on the ship unless $$\chi$$ and $$\beta$$ are precisely zero. Extensive research on this subject has been carried out by i.e. Wahab and Swaan (1964) [29].

Even with controls working there is a great danger of broaching in the above mentioned situation, a danger increasing with the wave height.
A reduction of the danger of broaching can be achieved by an increase of the fin area aft improving the smooth-water controls-fixed stability as shown by Eda (1972) [30] in Fig. 7 and by a right choice of the gain constants for steering control. For a more reliable judgment about the safety of the manoeuvrability of ships in waves, especially in following seas, experimental and theoretical research is required for the ship considered. The calculations should be carried out with a time domain model in six degrees of freedom including wind influence.

\[ y_f = \text{rudder force} \]

Fig. 7: Effect of rudder size in following sea. [30]

SEAKEEPING CONDITIONS

**Motions**

Extensive research on seakeeping since the sixties delivered useful knowledge for the determination of ship motions in regular and irregular waves. Many reliable computer programs were developed and may be used for optimization of the design or with respect to the operability of a ship in a seaway.

These computer programs are most commonly based upon strip theory (2D) or diffraction theory (3D) both starting from linearized potential theory. So, viscous effects are not included but should be added from experiments in particular for the rolling motion. Calculation and experimental verification of hydrodynamic coefficients like hydrodynamic mass and wave damping as well as wave forces together with their distribution over the ship’s length meant a valuable contribution to the development.

In this respect Gerritsma (1991) [27] should be mentioned who by means of forced oscillation technique determined the longitudinal distribution of the above mentioned parameters for a segmented ship model and found good agreement with calculated values, including shallow water conditions. After determination of the response functions of ship motions the behaviour in an irregular sea is obtained as shown in Figure 8 from Karppinen (1987) in [31]. This method may be used for all ship types and conditions with a restriction up to now for the following situations:

1. at high forward speeds: the relative motions
2. cases with viscous damping i.e. barges, shallow water
3. non-linear motions mostly introduced by high waves.
Chaos and capsizing

Danger of capsizing in bow or head waves is not of primary importance. Kaplan and Bentzon (1986) provided a mathematical model in six degrees of freedom as basis for a computer simulation to predict capsizing in steep head seas [32].

Non-linear large amplitude rolling in quartering and following narrow band seas is by far the most dangerous motion with respect to capsizing as already indicated before. Considering a single degree of freedom system sub-harmonic, harmonic (synchronism) and ultra-harmonic oscillations may occur at resonance frequencies as shown in Figure 9 from Francescutto (1991) [33]. Because of non-linearity the roll response curve will show a bended character leading to multi-valued responses for one frequency. See Figure 10 from Soliman (1990) [34].

Trajectories which do not lead to capsizing will eventually settle down to a bounded stable motion, for example periodic or sub-harmonic oscillations. Such a stable steady state...
motion is called an **attractor**. All starting conditions which generate trajectories that tend towards an attractor are defined as **basin** or domain of attraction. The combination of the domains of all the safe attractors is termed the **safe basin**.

Near resonance frequencies there is a region representing the unstable steady state response with typical jumps to resonance at a cyclid fold bifurcation (saddle-node). The trajectories are usually presented in a phase space diagram showing the roll angle and the angular velocity as demonstrated by Rainey and Thompson (1991) [35] in Figure 11. The shaded area is the domain of attraction or safe basin.

Non-linearity may be introduced by variation of the righting arm, variation of roll damping and/or variation of wave exciting forces in a transient wave train as shown in Fig. 12 [35] where the safe basin is suddenly eroded leading to
chaos and finally to capsizing. Such a dangerous situation may arise in sea conditions very near synchronism with heave or pitch. In this case there is even a strong sub-harmonic roll influence because the roll period is about two times the heave period, so that phase lag can play an important role.

It is therefore that Rainey and Thompson (1991) suggest in [35] that a useful way to quantify the stability of a given ship or ocean vehicle is to subject the model of it to a train of regular transient waves with increasing wave heights. The critical wave height or wave steepness can be plotted against the wave period for various fixed values of wave direction, heel angle and forward speed. This results in the Transient Capsize Diagram as shown in Fig.13 [35].

It is presented as an attractive fast procedure although it is only a first step in analysing the possibility of a capsize. In further research other influences such as those of current and waves should be taken into account.

It is also possible to obtain these Transient Capsize Diagrams by computer simulation taking advantage of recent developments in non-linear influences on the behaviour of ships and marine structures.

**Fig.13: Transient Capsize Diagram for a typical ship. [35]**

**Motion induced phenomena**

For the safety of marine vehicles ultimate conditions are of primary importance, but sound operational conditions may also contribute significantly to the safety of crew, passengers, ship and cargo. Violent motions and accelerations may cause serious degradation of the performance of the crew and less comfort or seasickness for the passengers. For cargo and ship, accelerations, deck wetness and slamming may lead to damage. If criteria for these phenomena are known or accepted prediction of occurrence and operability is possible in the way as shown in Figure 7 [31]. Although these seakeeping criteria are a subjective matter it appears useful to determine preliminarily such average criteria from a large amount of full-scale seakeeping data as was done by i.e. Karppinen (1978) [31]. Such root mean square criteria are presented in Table 1 [31] for the roll angle and the vertical and lateral accelerations as percentage of the acceleration of gravity g. Even for high speed planing boats the root mean square va-
lues for vertical accelerations may be determined by linear strip theory as shown by Blok and Beukelman (1984) [36]. For prediction of peak values, however, a non-linear approach in the time domain is essential as shown by Keuning (1992) [37].

Table 1: Criteria with regard to accelerations and roll [31]

<table>
<thead>
<tr>
<th>Root Mean Square Criterion</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vert. acc.</td>
<td>Lat. acc.</td>
</tr>
<tr>
<td>0.20 g</td>
<td>0.10 g</td>
</tr>
<tr>
<td>0.15 g</td>
<td>0.07 g</td>
</tr>
<tr>
<td>0.10 g</td>
<td>0.05 g</td>
</tr>
<tr>
<td>0.05 g</td>
<td>0.04 g</td>
</tr>
<tr>
<td>0.02 g</td>
<td>0.03 g</td>
</tr>
</tbody>
</table>

Depending on ship type or mission (merchant- or passenger ship) and place on board it is necessary to adapt the criteria of Table 1. For prediction of deck wetness the relative motion at a local position should be known which means a combination of the displacement because of ship motions, the wave elevation including the bow wave, and the dynamic swell up of the incoming waves due to the moving ship. In the operability predictions deck wetness is defined to take place when at a particular station the amplitude of the vertical relative motion exceeds the actual freeboard. To establish criteria, a permissible degree of deck wetness should be distinguished. Slamming (peak pressure due to impact) and deck wetness criteria have been defined in terms of critical probability (events per hundred wave encounters). The general operability limiting criteria often proposed are 0.03 for slamming and 0.05 for deck wetness. The critical number of slams per 100 wave encounters or the critical slamming probability against the length between perpendiculars for merchant ships is shown in Fig. 14 [31]. The restriction of this limit results mainly from fullscale data. In most prediction methods Ochi’s (1964) [37] definition of a slam has been used saying that slamming occurs if the foreship (at about 0.10L after FPP) emerges from the water and the vertical velocity relative to the water surface exceeds a critical value of

$$V_{cr} = 0.093 \sqrt{gL}$$  \hspace{1cm} (8)

with $L$ = length between perpendiculars  
$g$ = acceleration of gravity.

Fig. 14: The slamming criterion for merchant ships. [31]
For some cases, modern high-speed craft, this criterion based on the vertical velocity only is not sufficient. Recent research on wedges [39] hitting the water surface shows that the forward velocity also has a strong influence on the impact pressure while the highest pressures could only be observed at angles of about 1 to 2 degrees between hull and water surface. Prediction of these pressures shows proportionality to the squared vertical and forward speed. Besides local high pressure loads on the hull slamming also causes ship vibrations which in turn increase the total ship load significantly.

INTACT STABILITY OF HIGH SPEED CRAFT

Various types of advanced high-speed vehicles are achieving their high speeds by means of special design features or devices such as dynamic lift or fan-generated lift. The most commonly used types are shown in Figure 15 [28].

![Types of Advanced Marine Vehicles](image)

**ACV** = Air Cushion Vehicle  
**SES** = Surface Effect Ship  
**SWATH** = Small Waterplane Area Twin Hull.

Fig.15: Types of Advanced Marine Vehicles. [28]

For these types of vehicle separate treatment is required when dealing with intact stability for displacement condition generally at low speed, and operation at high speeds. When operating at low speeds in the hullborne or displacement mode the stability problems are almost similar to those of conventional displacement ships. However, although the requirements for adequate stability and buoyancy are similar, it holds that for the displacement mode these ship types show peculiar qualities such as low freeboard, large shifting of the center of gravity, influence of entrapped air pressure, etc. Specific intact stability criteria for advanced marine vehicles in the displacement condition for the U.S. Navy are presented by Goldberg & Tucker (1973) [40]. Planing boats, catamarans, etc. have a large transverse metacentric height GM in the displacement mode because of the beamy condition. Capsizing of multihull vessels, especially in high critical waves, is possible in spite of high initial stability and righting moment curve. Transverse stability and safety of most of the ship types are highly dependent on the extension of the GZ-curve and the area under the curve for heel angles greater than 50 degrees. At the high speeds for which advanced marine vehicles are designed the stability characteristics are quite different from the displacement condition. In comparison to conventional ships, high-speed vessels are much more sensitive to the influence of lift forces and air pressures associated with
motions in waves. From these influences a sensitive behaviour follows with respect to transverse and longitudinal stability, which might be controlled by simple means as shifting ballast, wedges, reducing speed or by more complicated means like transom flaps or horizontal control surfaces. Longitudinal stability, expressed as deck diving probability, is a very serious problem in following and quartering seas as shown by Jullumstroe (1990) in [41]. Reduced foil-lift due to wave particle velocity, out of water situations and pitch angle close to or larger than zero-lift angle may lead to bow-deck diving. This phenomenon occurs frequently for wave length ship length ratio's between 1.0 and 2.0 even in moderate wave heights if ship speed is equal or greater than wave speed. Model tests and computer simulation of deck diving in waves show good agreement [40]. However, it will be clear that it is hardly possible to design safety rules for all those ship types in different situations. The IMO-recommendation concerning stability of high speed craft is laid down in resolution A.373(x), 'Code of Safety for Dynamically Supported Craft' [42]. Transverse stability other than for hydrofoils is not covered by these recommendations, while longitudinal stability has not been taken into consideration.

CONCLUSIONS AND RECOMMENDATIONS

Future hydrodynamic research related to safety should be aimed at:

1. directional stability of fast ships in restricted water
2. chaotic non-linear behaviour in following seas
3. phenomena derived from motions, especially slamming, to take into account the danger of damage to the ship and degradation of the performance of crew and passengers
4. ship behaviour due to sudden water inrush.

In view of the necessity to consider the dynamic behaviour for ship safety, which is even more stressed for modern high speed craft and the impossibility to design rules and criteria for all ship types in dangerous and dynamic situations, it is advised to require for each ship(type) a certificate from authorized institutes or organizations. These institutes or organizations should with respect to ship safety also consider, if possible using preliminary criteria:

- directional stability in defined conditions
- probability of shipping water and slamming in certain sea-states
- degree of degradation of the performance of crew and passengers based on accepted acceleration criteria
motions and stability during water ingress
behaviour in transient following waves with different heights (Transient Capsize Diagram).

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Probabilistic evaluation of oil outflow from a tanker following side damage - relation to cargo tanks configuration
H. Vermeer

ABSTRACT
The paper gives an outline on the potential capability of an improved risk analysis as an instrument to be used in a safety policy for shipping on a consistent and continuous basis. In this context a desirable version of a data base of casualty statistics and the interface with the associated source of information (i.e. casualty records) is discussed. In order to visualize an effect analysis based on probabilistic principles the results of a small scale parameter study on 'hypothetical' outflow of an oil tanker after sustaining collision damage are presented. In this way the design of the cargo tanks arrangement may be accomplished by an optimisation procedure in terms of protection of the marine environment.

INTRODUCTION
The appraisal of an arbitrary ship design in terms of safety can be dealt with by some form of system analysis. Such a methodology may require an extensive risk analysis. Generally speaking the concept of risk is defined as the following mathematical product:

\[
\text{Risk} = \text{[Probability of occurrence of an event]} \times \text{[Effect of this particular event]}
\]

Practical application of the concept requires statistical information on the occurrence of primary events and a sophisticated 'mathematical' model based on either deterministic or probabilistic principles in order to quantify the effect of the event considered.

The primary events which are of importance to the safety of a ship (and the persons on board) may be listed e.g. as:

- Collision/contact
- Grounding/stranding
- Fire/explosion
- Foundering/capsizal
- Structural failure
- Etc.
Note: Human failure may represent a significant contribution irrespective of the primary events under consideration.

If preventive measures are considered to be taken it is of utmost importance to have detailed information on the particular conditions and features affecting the incident rate in order to ensure that the provisions intended are effective indeed.

The vast majority of such provisions, generated to warrant a minimum safety level, are accomplished as mandatory (international safety regulations and therefore casualty statistics shall be considered as an essential instrument for the purpose of pursuing a well-founded safety policy on a consistent and continuous basis.

Such a data base of casualty statistics should comply with the following requirements:

- The categories of primary events shall be defined in an unambiguous manner in order to avoid difficulties in interpretation.
- The sample shall be unbiased and as complete as possible which may be effected by the obligation of preparing a casualty record to be included in the data base.
- In order to enable trends to be identified additional information such as ship size, ship type, year of build, safety regulations (as applied), etc. shall be made available in a standardized form.
- For each primary event a record giving particulars which are relevant for the subject effect analysis shall be prepared.
- The casualty record shall preferably be a 'standard form' in order to facilitate access and up-dating of a computerized data base.

The effect analysis may be based on either deterministic or probabilistic principles. Bearing in mind that most input parameters, such as the environmental conditions and to a certain extent also the loading condition of the ship, are random in nature it may be concluded that most output parameters, such as ship motions and stresses, are stochastic processes represented by the associated probability distributions. In principle the probability distribution of an output parameter may be determined if the probability distribution of the input parameter and the response of the ship, either linear or non-linear, to all essential discrete values of the input parameter are known.

In general the response of the ship may be characterized as a stochastic process and there is a trend, which depends on
the state of the art and the acceptance by the parties involved, towards an increase of the application of probabilistic methods in the effect analysis.

This may be demonstrated with a topic of current interest i.e. the marine environmental protection of an oil tanker following collision damage.

**CALCULATION PROCEDURE**

The calculation procedure to assess the 'expected' outflow of an oil tanker sustaining collision damage may be based on probabilistic principles. The approach of this particular probabilistic method was introduced by Wendel (see ref.[1]) and has been developed along the lines of an effect analysis and is presently used for the subdivision and damage stability of some categories of both cargo ships and passenger ships. The most prominent feature of the Wendel-method is that the probability of flooding of an arbitrary compartment or group of adjacent compartments may be determined provided that the relevant (damage dimensions) statistics are available.

If the concept is applied then the contribution \( E_j \) of an arbitrary cargo oil tank to the expected oil outflow of the vessel is defined as the following (mathematical) product:

\[
E_j = \text{[Maximum amount of cargo oil } V_j \text{ to be carried in the cargo oil tank considered]} \times \text{[Probability } P_j \text{ that the cargo oil tank considered is involved in a collision damage]}
\]

where \( p_j \) (see also fig.1) can be expressed as:

\[
p_j = \text{[probability of a collision damage occurring anywhere along the length of the vessel with a penetration exceeding the value } b_i]\]

\[
- \text{[probability of a collision damage occurring anywhere along the length of the vessel aft of the cargo oil tank considered with a penetration exceeding the value } b_i]
\]

\[
- \text{[probability of a collision damage occurring anywhere along the length of the vessel forward of the cargo oil tank considered with a penetration exceeding the value } b_i]
\]

The probability \( p_j \) corresponds to the volume of the prism with the shaded area indicated in fig.1 as the base and the joint probability density distribution (of damage location and damage length) measured along the z-axis of the assumed orthogonal co-ordinate system.
The mathematical expression for the expected oil outflow of the vessel ET is presented in fig. 1 where the variables $p_i$ and $r_i$ have the following meaning:

- $p_i$ is the probability of opening only an arbitrarily assumed transverse compartment $i$
- $r_i$ is the conditional probability (reduction factor) that the damage penetration does not exceed the value $b_i$ to account for local subdivision of compartment $i$

The mathematical formulae for $p_i$ and $r_i$ are presented in appendix 1 and are based on the IMO damage statistics.

The basic assumptions which are relevant for the application of the proposed mathematical model, having in mind that it is intended for a comparative study, are summarized as follows:

- The damage is of a rectangular form.
- The probability density of the centre of damage location is uniformly distributed over the ship's length.
- The entire contents of a damaged oil cargo tank is spilled into the sea.
- The effect of very large damages, with an inherent very low probability of occurrence, leading to the complete loss of ship and cargo is underestimated.

In this respect it may be observed that ref.[2] deals with an alternative approach leading to the same result and with a more comprehensive discussion of the inherent assumptions.

In order to show the capability of the suggested method a systematic parameter study has been carried out.

**PARAMETER STUDY**

For the purpose of this parameter study a 'reference' ship is defined. The basic data of the reference ship and the associated cargo tanks arrangement are shown in fig.2. The parameter study consists of a systematic variation of the following parameters:

- non-dimensional cargo tank length
- non-dimensional cargo tank width
- non-dimensional double hull width

The calculations have been carried out on the basis of the mathematical model as given in appendix 1 and a summary of the results of these systematic calculations is given in appendix 2.
The results (expressed as a fraction of the cargo loading capacity $V_c$) have also been plotted in the figures 3-5 and give a clear picture of the effect of the systematic variation of the parameters on the expected oil outflow. The tendencies emerging from the figures 3-5 are not contrary to what could be expected.

Figure 3 shows that there is a linear relationship between the expected oil outflow and the cargo tank length.

Figure 4 shows the relation between the expected oil outflow and the cargo tank width. The effect of the pragmatic assumption $r(b_l/B_s=0.5)=1$ on the results is also indicated. Figure 5 shows that in the range of practical application there is approximately a linear relationship between the expected oil outflow and the width of the double hull.

The mathematical model and the way of presentation is such that the results may be generalized in such a way that the predictions for the expected outflow are valid for any ship size and cargo tank arrangement.

Quite recently other mathematical models (see e.g. ref.[3] and ref.[4]), also based on probabilistic principles but slightly different in the conceptual approach, have been developed.

**REMARK/CONCLUSION**

1. In order to warrant a consistent safety policy a reappraisal of gathering information on the basis of casualty records shall be considered. These casualty records shall be submitted on an obligatory basis and be in line with the needs of the associated effect analysis.

2. The expected oil outflow of a tanker after side damage may be estimated with an effect analysis based on probabilistic principles. This may lead to an optimum cargo tanks arrangement in terms of structural design and marine environmental protection assuming that the expected oil outflow is equal to the 'allowable' outflow.

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*****
APPENDIX 1

Formulae for $p_1$ and $r_1$ applied in the mathematical expression for the hypothetical outflow $E_T$:

\[
\begin{align*}
\frac{r_1}{L_1} &= \begin{cases} 
0 & \text{if } b_1/B_s = 0 \\
1 + (1-c_1) \exp\left\{-c_2\left(\frac{l_1}{L_s}\right)^{c_3}/(b_1/B_s)\right\} & \text{if } 0 < b_1/B_s < 0.5 \\
1 & \text{if } b_1/B_s \geq 0.5
\end{cases} \\
p_1 &= \begin{cases} 
\left(\frac{l_1}{L_s}\right)^2/0.24 - \left(\frac{l_1}{L_s}\right)^3/0.1728 & \text{if } l_1/L_s < 0.24 \\
\frac{10.5(l_1/L_s) - 1}{9.5} & \text{if } l_1/L_s \geq 0.24
\end{cases}
\]

APPENDIX 2

Scheme of systematic variations

<table>
<thead>
<tr>
<th>VARIATION OF $L_c/l_c$</th>
<th>$E_T/V_C$</th>
<th>VARIATION OF $B_c/b_c$</th>
<th>$E_T/V_C$</th>
<th>VARIATION OF $B_c/B_s$</th>
<th>$E_T/V_C$</th>
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</thead>
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</table>

* Reference ship
** Single hull concept
*** Effect of $r(b_1/B_s > 0.5) < 1$: $E_T/V_C = 0.1416$ for $B_c/b_c = 4$ $E_T/V_C = 0.2150$ for $B_c/b_c = 2$
FIGURES

Figure 1: Diagram showing the principle of the computation of the contribution of an arbitrary oil cargo tank to the hypothetical outflow

\[ E_T = \sum_j v_j \left\{ 1 - r_1 \left( \frac{l_1}{L_a} = l_f, b_i / B_a = b_i / B_a \right) \right\} \]
\[ -p_i \left( \frac{l_1}{L_a} = l_f / L_a \right) \left\{ 1 - r_1 \left( \frac{l_1}{L_a} = l_f / L_a, b_i / B_a = b_i / B_a \right) \right\} \]
\[ -p_i \left( \frac{l_1}{L_a} = l_f / L_a \right) \left\{ 1 - r_1 \left( \frac{l_1}{L_a} = l_f / L_a, b_i / B_a = b_i / B_a \right) \right\} \]

\[ V_C = \sum_j v_j \]
Figure 2: Basic data and schematic outline of reference ship

- $l_c/L_c = 0.20$
- $L_b/L_a = 0.15$
- $L_d/L_a = 0.10$
- $b_c/B_c = 0.50$
- $B_c/B_a = 0.80$

Figure 3: Graph showing the effect of a systematic variation of the non-dimensional cargo tank length

![Graph showing the effect of a systematic variation of the non-dimensional cargo tank length](image-url)
Figure 4: Graph showing the effect of a systematic variation of the non-dimensional cargo tank width

Note: $V_c$ is proportional to $B_c$

$V_c = L_c B_c H_c$

Figure 5: Graph showing the effect of a systematic variation of the non-dimensional double hull width
Integration of damage stability improvements in the design of Ro-Ro vessels
E. Vossnack, H. Boonstra

Introduction.

Ro-Ro passenger vessels have commercially proven to be a very successful type of design, not in the least because the car decks stretch from board to board and from stem to stern, thus diminishing the time required for loading and unloading passenger cars and lorries. That this leads to poor damage stability characteristics of Ro-Ro vessels was already long recognized in the marine community, but it was only after the disaster with the 'Herald of Free Enterprise' that serious research programmes were initiated to improve the safety. This accident and the research has also led to considerable amendments in the damage stability rules (Solas '90) for Ro-Ro vessels. This paper reviews various ways which have been proposed to improve the safety and compliance with the new criteria. It highlights a solution in which permanent reserve buoyancy is created in the sides of the ship, directly below and if possible, also above, the bulkhead deck. This option provides for permanent buoyancy in the sides in case of a collision and also decreases the penetration depth. Furthermore the inrush of water after a damage is retarded by the presence of buoyant material, which diminishes heeling angles in intermediate stages. Investigations and research required to support this solution are discussed.

General stability characteristics of Ro-Ro passenger vessels.

During the past decades Ro-Ro passenger vessels have evolved to very wide and flat ships with almost barge-like midship sections. Typical B/T ratio's vary between 4 and 5 and the freeboard of the lowermost car deck (bulkhead deck) is often only 2.0 m or even less, say 7 or 8 percent of the width of the ship. This low freeboard is allowed according to ILLC regulations because of the large superstructure, which extends in most designs over 70 or 90 percent of the ship length and results in an enormous reserve buoyancy in intact condition. A typical cross section is shown in Figure 1. Because of operational requirements and flexibility (fast loading and unloading of lorries and passenger cars, and consequently short port times) the car decks directly above the bulkhead deck stretch from board to board and from stem to stern without any bulkhead or obstruction. Consequently, when for one reason or another the hull is damaged (or when a bow door is not closed, as in case of the 'Herald of Free Enterprise') the reserve buoyancy above the bulkhead deck has completely vanished. The low freeboard results in an immersion of the bulkhead deck at an angle of heel of say 8 or 10 degrees when the ship is in intact, even-keel condition. With flooded compartments and/or trim the angle of immersion of the bulkhead deck may become considerably smaller. Once this deck is immersed sea water can enter into the ship on the bulkhead deck. The lever arm of stability very soon will become negative and the vessel is likely to capsize, as is proven in model tests (Pucill [1]) as well as in reality (Spouge [2],[3]).
Safety considerations.

Several comprehensive surveys on safety aspects of Ro-Ro vessels have been published in the recent past, see for instance Spouge [3] and Lloyd [4], to mention just two of them. The general conclusion is that although the risk of individual passengers travelling on ferries in the western world is extremely small and certainly acceptable when compared to other forms of public transport. However the large numbers of casualties which can occur in one single occasion is not accepted by society. In case of the ‘Herald of Free Enterprise’ disaster at least 193 people died and in a worst case scenario the number of casualties may exceed 2000. Designers and owners of Ro-Ro vessels have been criticized by the way they treat safety aspects. One point of criticism is that only a few obvious potential hazards are considered in the design and operation of the vessel and that these hazards are treated separately and are often only checked against regulations.

In other sectors of the industry, notably in the design of nuclear power plants and petrochemical installations, an integrated systematic risk-analysis is applied from which often unexpected interactions between causes and events can be found and a balance between various types of risks can be established. Also in offshore engineering (Thompson [5]) this type of risk analysis has proven its value and will, certainly for the more complex installations as floating production facilities, become mandatory in the near future.

Another point of criticism is that engineers tend to forget to include human behaviour in the safety analysis. This omission results in an underestimation of the risks involved and does not lead to the heart of the matter when it comes to measures to improve the safety in the future (Wagenaar [6]). Both points of criticism should be taken seriously by naval architects and may well result in a change in regulations, tools and attitude towards safety in the industry in the near future.

However it may be, still pure technical improvements in the design, the structure and the lay-out of the ship can help to improve the safety in case of a serious collision. Such an improvement more or less automatically will effect the outcome of a risk-analysis as the consequence of an event tree will be less detrimental.

Damage stability regulations, present situation.

Until recently the damage stability requirements for Ro-Ro passenger vessels were in principal based on the 1960 SOLAS convention for passenger vessels, which stipulated that in the final damaged condition the bulkhead deck should remain 76 mm clear of the still waterline, the angle of heel should be smaller than 7 degrees and that the metacentric height in that situation should be at least 50 mm. In later years it was realized that also asymmetrical flooding and intermediate stages of flooding should be investigated. Minimum requirements regarding the maximum angle of heel in intermediate stages were formulated in the 1974 SOLAS convention. It was also realized that the 50 mm metacentric height in damaged condition did not give sufficient safety, which resulted for instance in the 1984 UK Passenger Ship Regulation and the requirements by the Dutch Shipping Directorate of 1983 in which a minimum positive range of stability of 7 degrees was specified in combination with a minimum area of 0.004 m rad. under the GZ curve.

Soon after the ‘Herald of Free Enterprise’ disaster an international agreement on higher standards of residual stability was reached. These so called 1990 SOLAS requirements stipulate for the final condition after damage (Fig. 2):

- A minimum range of 15 degrees, starting from a maximum angle of 7 degrees for one compartment flooding or a maximum of 12 degrees for a two compartment flooding.
- The area under the GZ curve shall be at least 0.015 m rad.
- The maximum GZ shall not be less than 0.10 m.
The majority of present day Ro-Ro vessels do not meet these higher standards as was shown by White [7]. This also implies that new designs should have considerably better damage stability characteristics than existing vessels. Model tests with a damaged vessel in waves performed by Pucill [1] indicates that a significant wave height between 1.0 and 1.5 m can be survived when the 1990 SOLAS requirements are met. Such wave conditions are quite often exceeded at open sea, so if these tests are representative for Ro-Ro passenger vessels it can be questioned whether the new regulations are sufficient to provide an acceptable margin of safety.

However of greater importance than the final condition is the large heel which may occur during the first 20 or 30 seconds after a side collision due to transient asymmetric flooding, sluggish cross flooding and in the worst case topping of trailers (Fig. 3). The size of the hole (or holes) punched in the hull by the bow and/or bulb of the colliding ship is of decisive importance for the transient behaviour after the collision.

Proposals for improvement of damage stability characteristics.

In order to comply with the new SOLAS '90 stability rules several modifications in the lay out and/or compartmentation of Ro-Ro vessels have been proposed in the recent past. A paper by Lloyd [4] gives an almost complete overview of some 15 alternatives and the paper also reviews their effectiveness in meeting new stability regulations and consequences for costs and operations. Of these proposals some are of interest for existing ships, others are only applicable in new designs. The most notable suggestions are:

- **Retractable transverse barriers above the car deck.**

  The idea is to arrange a watertight subdivision of the vessel above the bulkhead deck with a number of movable barriers which are subsequently closed after part of the deck is loaded. The effectiveness of the system is uncertain and it is difficult to make it fool-proof, but even if it is possible to design sufficiently robust and reliable barriers, operational problems and a loss in time and effective stowage area is foreseen.

- **Longitudinal watertight bulkheads above the car deck.**

  Longitudinal watertight bulkheads above the car deck will only be effective when the wing space between the bulkhead and the outer hull is subdivided by narrowly spaced transverse bulkheads or water tight doors (see Brown [8]). This means that the space can not be used effectively for cars. It has been proposed to use the wing space for trailers which are brought in place by a tugmaster. Watertight doors are provided fore and aft of each two 40 ft trailers. Although the system increases the survivability of the ship, it does not result in a very attractive and flexible lay out of the car deck.

- **High stability hull form.**

  By applying 'V' rather than 'U' shaped sections in the lines plan of the ship the KM value is increased and hence, with an unchanged VCG, the initial stability is increased as well as the GZ curve. The improvement in stability can then be used to increase the freeboard of the bulkhead deck (with, of course a consequential increase in KG due to the fact that all weight items of the ship and cargo above the bulkhead deck are moving upwards). However in practice the improvement in damage stability characteristics will be limited, in particular when a reasonably conventional lines plan is desired.

  The most simple solution is to increase the freeboard by decreasing the draught,
which means a reduction of payload. Another way is to increase the width of the ship, thus creating a large metacentric height, resulting in a stiff ship and high accelerations.

- **Sponsons.**

By adding sponsons to an existing hull the damage stability characteristics of the vessel can be improved considerably. In order to avoid asymmetrical flooding after a side damage it is required to subdivide the sponsons by a large number of transverse bulkheads or alternatively provide for permanent buoyant material in the sponsons. Major disadvantages of sponsons are the adverse effect on rolling motions due to increased GM, the increased resistance and, depending on the port, clearance with quay walls or locks of the ferry terminals. Also the lowering of lifeboats may be hampered by the sponsons.

The authors believe that with only conventional adaptions to the design of Ro-Ro vessels improvements in the safety will remain marginal. The safety can however be improved considerably when the outside part of the ship over a reasonable range of height near the waterline virtually cannot be flooded, even after a high impact collision. Such a solution will be elaborated in the next section.

**Buoyancy in the wings.**

The idea of application of permanent buoyancy in the sides of a Ro-Ro vessel is suggested by Vossnack [9, 10]. One possibility is shown in Fig. 4. The vessel is provided with longitudinal bulkheads at approximately 0.2 B from the sides. When the wing tanks are left empty large cross-over ducts are required to avoid asymmetric flooding in case of a side collision. Recent research into the transient behaviour of damaged ships with longitudinal bulkheads and cross-over ducts between the wing tanks has improved the possibility to predict the dynamics and judge the stability in the first minutes after a collision, see Vredeveelt [11]. However this research has also shown that the dynamic effect may cause considerable angles of heel even when large cross-over ducts are installed. The safety in case of a collision would therefore be improved if the wing tanks were provided with buoyant material like foam or empty steel drums, thus achieving a permeability of the wing tanks of between 10 and 30 percent. Another positive effect of the presence of the material is that the ingress of water is slowed down (Fig. 5, top). The pros and cons of different types of material are discussed in a next section.

The foregoing proposals are valid for passenger Ro-Ro vessels where side compartments below the bulkhead deck are not used for water ballast or fuel oil and must remain empty in order to fulfill damage stability requirements.

However for Ro-Ro cargo vessels the wing tanks below the bulkhead deck may be needed for ballasting purposes or storage of fresh water or fuel, and cannot be filled up with buoyant material. Therefore instead of a configuration as shown in Fig. 4, the buoyant material could be provided inside wing tanks above the bulkhead deck (see Fig. 6) or both above and below the bulkhead deck (Fig. 7). In most cases a width of 0.10 B of the wing tanks will be sufficient to maintain a positive metacentric height in the final condition with the complete car deck flooded. Although in the first instance after the collision the metacentric height may be negative, an improvement of the metacentric height is achieved when the water accumulated on the car deck is dumped onto the tanktop of the lower hold or, if possible, into void tanks in the double bottom.
through large diameter scuppers, (Fig. 5: top right and bottom).

The compartments with buoyant material above the bulkhead deck obviously reduce the space at the car deck. This disadvantage is relative only, because the new damage stability regulations require changes in the design (like a raising of the bulkhead deck) which cause a decrease in cargo capacity anyhow. Furthermore the wing tanks do not hamper the operational flexibility of the vessel. Another advantage of buoyant material in the wing tanks is that in case of a side collision the depth of penetration is decreased. In the next section some preliminary results of a pilot test to investigate the energy absorption of these materials are discussed. For existing vessels a retrofit by means of structural sponsons filled with buoyant material may, in most cases, be an acceptable solution (see Fig. 8).

**Buoyant material.**

If buoyant material is to be applied in the wing tanks of a ship, the following requirements have to be fulfilled:

- the material must have a low specific weight
- the material shall be inflammable and shall not produce toxic gasses when it is exposed to heat
- the material must have sufficient compression resistance to withstand the maximum water pressure in case of damage
- installation and removal of the material must be simple
- inspection and access to appendages inside the tank must remain possible

The following materials are considered to be more or less suitable for the purpose:

- **Blocks of phenol formaldehyde foam**

  The specific weight is approximately 50 kg/m$^3$. The material is thermo-hardening, fire proof and does not produce poisonous gas when heated. It can be covered by perlite, an inert, volcanics material consisting of micro-balloons of glass.

- **Blocks of polystyrene hard-foam**

  The specific weight is approximately 20 to 30 kg/m$^3$. The material is thermoplastic, melts when exposed to heat above 90°C, therefore it probably has to be shielded by means of eg rockwool blankets or by phenol/perlite blocks. Polystyrene hard-foam blocks are used for various civil engineering works on shore.

- **Empty metal drums**

  The specific weight is approximately 60 kg/m$^3$. The stowage is less efficient than the stowage of synthetic blocks. The material is fire resistant but the thin steel wall is sensitive for corrosion.
Penetration tests on a schematic double hull configuration with different types of filling.

One of the positive effects of filling side compartments with buoyant material is the absorption of kinetic energy in case of a collision. The presence of the material will result in a substantial smaller penetration depth of the bow of the colliding ship. It is however extremely difficult to quantify the effects. Only recently investigations are undertaken to correlate strength calculations based on non-linear finite element time domain analysis of ship collisions with full scale tests, see eg Vredeveldt [12]. In due time this type of analysis will provide engineers with the tools to predict damage due to collisions and to design more robust structures. These calculations and tests of course only include the steel structure of the ships. In order to obtain an estimate of the energy absorption of permanent buoyancy fitted in side tanks, a number of simple pilot tests have been carried out recently in the Netherlands, sponsored by a consortium of companies and the Dutch Foundation for the coordination of Maritime Research CMO. In the tests a schematized hull section consisting of 7 mm plate with stiffeners (HP 120*7) is placed horizontally on a stiff closed box. The plate is hit by a hammer of 3.5 ton, falling from 10 m height, which simulates the impact of a collision. The space enclosed by the plate and the box is in one case empty and in other cases filled by various types of buoyant material. After each test the stiffened plate is renewed. See also Fig. 9. The penetration of the falling object as well as the load at the bottom plate are measured. The penetration is a measure for the energy absorbed by the filling material and the load on the bottom plate indicates whether the inner hull would have been damaged. The preliminary results of the tests are encouraging. In particular polystyrene foam appears to limit the penetration to a great extent. Detailed results will be reported by TNO Centre for Mechanical Engineering in the near future [13].

Future research required.

Based on its properties and the capability to absorb kinematic energy in case of a collision polystyrene foam is considered to be the preferred material for the creation of permanent buoyancy in the wings of the ship. However if fire resistance is required phenol formaldehyde is a good alternative.

Further investigations are required about the following aspects:
- improvement of heat resistance of polystyrene foam eg by shielding of the material by rockwool sheets or phenol formaldehyde covered by perlite
- development of computational model to predict the energy absorption of hull sections filled with buoyant material

Conclusions.

- Ro-Ro vessels are, due to the low freeboard of the bulkhead deck and un-obstructed cargo deck, prone to rapid capsize after a side-collision.
- The size of the hole (or holes) in the side of the vessel is of great importance for the transient behaviour of the vessel in the first tens of seconds after the collision.
- Permanent buoyant material in the wings of a Ro-Ro vessel has positive effects on the
- it limits the penetration of the bow of the colliding ship
- it hampers the inrush of floodwater and consequently improves the transient behavior immediately after the accident and reduces the heel of the vessel
- it ensures a considerable moment of inertia of the water line area and thus reduces the danger of capsizing

Foam material like blocks of polystyrene or phenol formaldehyde seems the best solution to create permanent buoyancy.

Permanent buoyancy can be used in other types of vessels as well to improve the safety in case of damage. Examples are: catamaran, swath, semi-submersibles, etc.

References.


Pass. cars

Fig. 1 Cross section of a Ro-Ro passenger - car vessel.

Fig. 2 Damage stability standards for passenger ships (SOLAS 1990).

FIRST MINUTE:

- The rapidly increasing list caused by water rushing into the ship after a hull-penetration requires close attention.
- Crossflooding may be sluggish and is effective only in case the ship has a positive righting moment.
- The forecast will be immersed if listing continues and water, entering via a hole in the topside of the ship, will spread out over this continuous deck.
- This sequence of events may lead to capsizing if downflooding of entered water is too sluggish.

LARGE HEEL IN 8-20 SEC.

HEEL CURVE

DEPENDS ON:

SIZE OF HOLES
G.M. DAMAGED
CROSSFL. DUCT
DOWNFL. SUPP.

AS SOON AS THE ATTACKING BOW IS RETRACTING

OVERFLOW TIME:
BY DUTCH: 60 SEC - WIDE DUCT
ITALIAN RINA: 15 - IMPOSSIBLE TO REALIZE
SOLAS 71-76: 15 MINUTES!!!

CROSSFLOODING UPHILL IS RATHER SLUGGISH

FLOW RATE: 71 ft³/sec - 21 sec
INFLUX: 595.2 ft³/sec - 400 ft
= 60 - 1000 ft

PROPOSED IS A "STANDARD" HOLE

Fig. 3 Flooding after a collision.
Fig. 4 Permanent buoyancy under car deck.

Fig. 5 Effect of hardfoam blocks in the wings (top); down-flooding and cross-flooding arrangements (bottom).

Fig. 6 Permanent buoyancy above car deck.
Fig. 7 Permanent buoyancy above and below car deck.

Fig. 8 Existing Ro-Ro vessel fitted with sponsons and permanent buoyancy.

Fig. 9 Arrangement of energy absorption tests.
Some observations on the safety of Surface Effect Ships
R.J. de Gaaij, M.J.H. Slegers

Abstract

The paper describes the IMO A373(X) requirements for high speed craft and the proposed revision of the code. The code shall be updated by IMO, to be in line with the actual safety philosophy and developments in craft size and application. The requirements with respect to safety effect analysis and fire safety tend to get stricter. The requirements will shift towards the aviation type of approach with respect to e.g. manuals, propulsion redundancy and crew training.

The safety aspects of Surface Effect Ships are qualitatively compared to other high speed craft, which leads to the conclusion that Surface Effect Ships have the same level of built-in safety as catamarans. The effect of the revised code may be a higher lightweight, and as a result, the economical benefits of high speed craft may strongly diminish.

1. Introduction

During the last decade we have seen a tremendous increase in number of high speed craft, especially for ferry services. The service speed of these vessels steadily increased, from 25 knots some years ago to 35 knots or more nowadays. Looking at the application of high speed craft in congested areas, such as major cities and inter island transportation, the aspect of safety should be well considered. Until now this type of passenger transport has shown to be rather safe, but with more and more craft, be it high or low speed, the necessity for the Authorities to come up with stricter rules and regulations is increasing.

In this paper some safety characteristics of Surface Effect Ships are described and related to those of other high speed craft.

2. International Rules/IMO Rules

Special rules for high speed light craft were published by IMO in 1977 as 'Code of Safety for Dynamically Supported Craft' A373(X), to be applied instead of the more common SOLAS rules and International Loadlines convention. The SOLAS safety philosophy is based on the assumption that the vessel is made of steel, which is normally not the case for high speed light craft. The present A373(X) code is based on the following premisses:
- The worst sea state for which operation will be permitted, is restricted;
- There will at all times be a reasonable proximity to a place of refuge;
- Adequate provisions will be made for communication so that any accident to the craft will be quickly known to the base port;
- Facilities are provided for rapid evacuation into survival craft;
- Rescue services will be rapidly available throughout the voyage;
- Reliable weather forecast for the area concerned will be available;
- Acceptable maintenance and inspection facilities together with adequate control arrangements are available;
- Strict control over operations will be enforced;
- All passengers are provided with a seat and no sleeping berths are provided.

The actual code was applicable to craft within the following boundaries:
- carrying more than 12 passengers but not over 450 passengers,
- Froude number in excess of 0.9,
- the maximum distance to a place of refuge is 100 nautical miles, and
- the ship's weight or a significant part thereof is balanced in the prevailing mode of operation by other than hydrostatic forces.

The Administrations shall check these requirements and issue a 'Dynamically Supported Craft Construction and Equipment Certificate' for the craft and a 'Permit to Operate' for each specific route.
Where any of the above does not apply, the Administration should consider whether equivalent safety can be achieved in another way. Quite some room for interpretation is left to the Administrations, which leaves it to the designer and owners to find out per case which additional requirements are to be met. Both for yards and owners it is of vital importance to have a craft that can be applied on routes all over the world without major modifications, and which complies with domestic legislations. We propose an international accepted code in the form of a handbook, comparable to the BHSR handbook.

This liberty of interpretation of the Administrations, together with the ongoing revision of SOLAS requirements, and the growth of passenger capacity of high speed craft, has urged the IMO to revise the A373(X) code in the near future. This revised code shall be read 'Code of Safety for High Speed Craft', and be applicable to all high speed
craft. The code shall allow the application of developments in technology and be applicable to new concepts aiming at safe and comfortable transport. The intention of the revised code will more than in the existing code be aiming at determining safety and operational standards by use of safety levels and performance criteria. Thereto verification methods shall be defined, more or less adapted for each type of craft.

The revised code will probably contain the following requirements:

- Craft speed shall be in excess of 25 knots.
- The craft shall be of lightweight construction. No definition is yet agreed upon.
- No dangerous goods are allowed, only special category spaces intended to carry motor vehicles with fuel in their tanks may be included.
- The shortest distance to a place of refuge shall be restricted by imposition of operational limits.
- A failure effect analysis (FEA) will be mandatory.
- The designer shall be obliged to supply sufficient information to enable the Administration to fully access the features of the design.
- Fire safety requirements shall be met, based on two alternative philosophies, as discussed below.
- The management of the company must ensure that only personnel qualified to operate the specific type of craft used on the intended route are employed. This will have impact on the educational requirements and updating courses for the crew.
- The management of the company operating the craft shall provide the craft with adequate information and guidance in form of manuals enabling the craft to be operated and maintained safely.

The revised code will not set limitation to the number of passengers carried. Furthermore the existing and revised (draft) codes are applicable to passenger transport only. Other applications of high speed transport, such as transport of cargo by trucks, trailers, containerized products, are not (yet) covered. Meanwhile these type of vessels are already being marketed!

Proposals for the scope, philosophy and applications of a revised code as set up by representatives of Administration of several countries involved in high speed craft applications, shall in time be discussed by all interested parties, e.g. industry, shipping companies, classification societies and administrations.
The Royal Institution of Naval Architects has recently organized a seminar in order to stimulate a horizontal discussion, instead of the vertical discussion where shipowners, designers, builders and classification societies submit their comments to the national Administrations, before conferring it at international level.

Another attempt to structure the discussion was initiated by Det Norske Veritas Classification, to start an international committee on high speed and light craft in 1991, with participants of ship designers, shipyards and maritime authorities.

3. Fire and Flooding Survivability

The revised code allows two philosophies regarding evacuation, as explained below.

The first is according to the existing code, which is based on the assumption of immediate evacuation of all passengers and crew, assisted by external rescue services, allowing an evacuation time of 7 minutes and 40 seconds maximum. Furthermore the code sets a requirement on the local infrastructure, e.g. communication and rescue services. Looking at the new generation of high speed craft, this is not always realistic.

Figure 2 shows an escape slide arrangement according to the envisaged evacuation time of 7 minutes for 450 passengers onboard the SEASWIFT 60.

The requirements on the number and size of ordinary exits and emergency exits and the means of escape into survival craft shall be considered. Probably the means and arrangements for evacuation shall be tested in more realistic emergency training situations to measure the evacuation time, as already practised in a number of countries. Regular fire drills of the crew will be arranged. Figure 1 shows an evacuation trial onboard the SEASWIFT 23.

The second approach will be to determine the fire and floating survivability of (larger) craft so as not to immediately evacuate all passengers. In the choice of approach, the availability of rescue services on short notice is also considered.

This will imply a subdivision of the accommodation in such a way that the occupants of any compartment can escape to an alternative safe area or compartment in case of fire. In such case the craft shall be able to handle the situation by itself, by providing a safe accommodation of the persons onboard and by maintaining the operation of all main
functions on board even in case of fire in one major compartment. For larger vessels this might be no real problem.

Enclosed spaces such as galleys, shops, cinema's and restaurants are not permitted. However refreshment kiosks are allowed. In the revised code, again no enclosed passenger sleeping berths are allowed.

Special category spaces, such as car decks, will be treated as areas of major fire hazard, as a fire may be expected and will develop immediately. Furthermore areas of moderate fire hazard, such as crew accommodation and control stations are defined as spaces where a fire may develop from a local fire. Third, areas of minor fire hazard, such as accommodation spaces, are defined, where a fire is not expected to start or to develop.

Fire resisting bulkheads and ceilings shall be constructed to resist exposure to the standard fire test for a period of 30 minutes for areas of moderate fire hazard and 60 minutes for areas of major fire hazard. Passenger accommodation areas, including service spaces, shall be protected by a fixed sprinkler system (controlled from the navigating control station). At least two independent water fire pumps shall be arranged. Areas of major and moderate fire hazard shall be provided with an automatic smoke detection system. Main propulsion rooms shall in addition have a heat detection system.

In areas of major hazard, such as car decks, fixed quick acting fire extinguishing system and a TV monitoring system shall be provided.

This new subdivision in category spaces with stricter fire division requirements will be valid for both fire safety philosophies.

This revised code will impose a large influence on projects of larger high speed craft projects with respect to the internal arrangements and the ship's lightweight and as a consequence will drastically influence the payload. As the speed of a SES is even more sensible to displacement variations than a catamaran, this aspect needs careful consideration.

Looking at the number of accidents with high speed craft it can be noted that severe accidents, involved mainly navigation and system failures and not fire or flooding. Therefore to our opinion the existing code seems adequate for small high speed craft, operating in coastal waters.
4. Failure Effect Analysis (FEA)

Looking at the latest designs of high speed craft and considering the introduction of dynamically controlled stabilization systems and sophisticated automation systems, the Administrations feel the urge to outline a method ensuring the vessel's safety, by the use of failure mode analysis in the design process, while the final craft's performance shall be verified. In the present code the failure mode effect analysis is already mentioned for some specific systems, i.e. machinery and steering. In the revised code the failure mode effect analysis will be applied much stricter and be applicable to all main machinery and components.

The focus will shift towards more and stricter operating and safety procedures in order to prevent serious accidents in the future.

With respect to reliability of the propulsion machinery, experience has learned that the actual level is not acceptable for the operators, especially for the main engines that are a.o. too highly loaded. This will probably also have an impact on the Classification Society's philosophy. The failure of one propulsion system will however normally not directly effect the vessel's safety.

This tendency to require stricter FEA is growing, a.o. due to some accidents with high speed craft in the past year. One accident with two passengers killed took place on November 4th, 1991 in Bergen, Norway where a catamaran hit a rock at full speed, because a lightbuoy was observed too late: the occulting light frequency was not adequate for the high craft speed. One important conclusion drawn will be the development of performance standards for high speed craft navigational equipment. Furthermore a requirement for two navigators with two independent radar systems is considered. Developments have started on ergonomical improvements of bridge designs.

Another severe accident involving a high speed catamaran concerned the 'Apollo Jet' in Hong Kong, which also resulted in proposals for stricter operational procedures. In this case the catamaran lost control of the engines and the steering of the waterjets and collided with two moored vessels and ran aground, killing four people and seriously injuring another seven.

The Marine Court in Hong Kong notes: "Reliability of control circuits for each and every dynamically supported craft should be confirmed on a practical basis every year after its annual survey - and prior to granting a speed exemption"
Stricter procedures will also imply the preparation of operating and maintenance manuals, according to e.g. UK Department of Transport requirements. The latter refers to requirements formulated by the Civil Aviation Authorities as the 'British Hovercraft Safety Requirements' for hovercraft vehicles, and also, as a consequence of definition, applicable to Surface Effect Ships.

One problem might be to keep the manuals user friendly, in order to be adequately used by the crew themselves.

It seems that the requirements on FEA tend to some airline industry type of operation. However opposite to aircraft industry, the feedback of experience and information concerning hazardous occurrences from operators to designers and regulatory bodies is not structured.

5. Safety of Surface Effect Ships

The safety of a Surface Effect Ship is very much the same as a comparable high speed catamaran. However with SES speeds, of 40 to 50 knots, which are much higher than average catamaran speeds, the necessity for strict safety analysis is felt even more.

In comparison to high speed monohulls, the intact and dynamic stability is better. Other safety aspect may be comparable.

The advantages of a Surface Effect Ship are listed below:

- good intact stability: high metacentre, large stability range
- high damage stability: 2 compartment type, with limited heel and trim in asymmetric damaged conditions.
- high redundancy: two independent propulsion systems and the craft can remain afloat on-cushion with any compartment damaged
- low crew fatigue: relatively low level of vertical accelerations
- failure effects: a SES is intrinsically safe; no active foils, flaps, skirts or other stabilization system can affect the vessel's safety control. The loss of the air cushion will only result in a deceleration and a return to the off-cushion (or catamaran) mode of operation.
- good dynamic stability: The vertical centre of buoyancy is
within the critical limits. A modern SES tends to heel inward in high speed turns and gives therefore a high degree of safety.

6. Conclusions

The number of accidents with high speed vessels involved show that this kind of transportation is a very safe one. The IMO requirements for dynamically supported craft dating back to 1977 are being revised, and tend to be much stricter. The revised code will emphasize to the application of failure mode analysis and operational procedures, more comparable to aircraft industry.

As the speed of a Surface Effect Ship is very sensitive to weight variations, the weight penalties of additional requirements resulting from the revised draft code shall impede the high speed potential of Surface Effect Ships.

In parallel to the development of high speed craft, the supply industry shall be forced to develop equipment and materials adapted to the IMO codes. This can only be enhanced by a flourishing high speed market.

The safety of Surface Effect Ship is not very different from other high speed craft. The SES design is intrinsically safe, but due to the very high speeds, the requirements on navigational safety and system failures must be strict.

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Figure 1. Evacuation trials onboard the SEASWIFT 23 of Royal Schelde in Vlissingen.
Figure 2. Escape slides arrangement onboard the SEASWIFT 60 of Royal Schelde
Advances in safety technology applied to marine engineering systems
T. Ruxton, J. Wang, E.D. Watson

ABSTRACT — This paper is concerned with the problems associated with marine safety analysis and attempts to integrate design for safety into the practical marine product design process. Safety analysis techniques are used to identify risks and to evaluate system safety and reliability both qualitatively and quantitatively. Safety criteria, assumptions and the requirements for modelling safety systems for design analysis are addressed. With regard to industrial practice, the phases for marine engineering system design from a safety viewpoint are studied, and an illustrative example is used to demonstrate a design for safety framework. The analysis methods and modelling techniques used in this paper may be used for the design of complex marine engineering systems.

1. INTRODUCTION

1.1. Engineering design methodologies

Three design methodologies which may be used for the design of various marine and other made-to-order (MTO) products have been identified as 1. original, 2. adaptive and 3. variant. Original design is to produce an original solution for a system to carry out a new task. Adaptive design involves adapting a known system to a changed task. Variant design is to vary the size and/or arrangement of certain aspects of a chosen system. Patterns within each of individual philosophies and engineering disciplines can be identified and analysed from a series of steps or frameworks for organising and guiding a design. Such a framework is referred to as a design methodology.

In relation to these methodologies, two distinct levels of design activity can be identified 1. a conceptual stage and 2. an embodiment stage. The conceptual design phase essentially requires design engineers to examine the problem statement and generate broad-based solutions to it. The embodiment design phase requires that the most promising candidate solutions are developed in greater detail with the final selection being based upon relevant technical, economic and safety criteria. Generally, a framework covering the design process can be expressed by stages such as clarifying objectives, establishing functions, setting requirements, generating solutions, evaluating alternatives and improving details.

The benefits of the methodology are obvious. These include rapid and direct generation of design solutions and the evaluation of these solutions. A rational and systematic framework can make the work of design engineers more efficient and effective.

1.2. Current status of design for safety methodology for mechanical/electrical (M/E) systems of marine products

The objective of system safety design is to provide assurance that the system will operate safely as intended by evaluating all aspects of the total system design from a safety viewpoint. System design for safety provides a systematic approach to the identification and control of high risk areas. Although design for safety methods were introduced in the aerospace, nuclear and chemical process industries many years ago, a series of standards, covering the general use of reliability throughout industry, were issued from 1980 (2, 3). The techniques described in these standards are applicable to M/E systems design of marine products.
Safety considerations have always been a matter for concern during marine design. However, research shows that design for safety of most M/E systems of marine products is usually based only on British standards and classification society requirements (or the equivalent), which incorporate the necessary factors of safety. Due to the complexity of safety analysis and lack of complete guidance for a design for safety methodology, design for safety has not been specifically integrated into the design process. It is worth noting that the deficiencies in many marine product designs are only corrected after accidents have occurred, and few organised safety design programs devoted to marine design have been devised and implemented. Many accidents, even those involving human error, could have been prevented if the design had been different. Therefore, there is a requirement for design for safety applied to marine products with a primary emphasis during the various design stages in order to obtain optimum safety.

For some years SERC (U.K. Science and Engineering Research Council) and U.K. industries have financed research projects in design for reliability and safety, the objectives of which were to develop practical procedures to quantify and incorporate safety as an integral part of the design process. Problems that have been identified include a lack of valid data and inadequate cooperation between industrial design engineers and safety programme researchers. Current research in design for safety at the University of Newcastle upon Tyne is focused on providing systematically derived information upon which rational decisions may be made. Analytical tools which can provide an insight into the problems involved and also extend the designers capabilities are being developed to provide a facility to design marine products safely, efficiently and economically.

1.3. Objectives, requirements and constraints of safety design methodologies for M/E systems

The objective of mechanical/electrical (M/E) system design for safety methodologies is to provide a framework for qualitative and quantitative safety analysis to be carried out. The general requirements of the M/E system design for safety methodologies are that they should not conflict with the general design process and its criteria, and therefore be consistent with a general products design methodology.

For M/E safety system design some simplifications and assumptions should be made to facilitate easier methods of analysis. The problem of a scarcity of mathematical methods for design for safety causes difficulties in applying the safety design techniques demanded by those concerned with marine accidents. However, it is generally agreed that proper appraisal methods for assessing safety and reliability of marine products are required in order to keep pace with the advance of technology.

2. DESIGN FOR SAFETY

2.1. Criteria

It is very difficult to judge the safety of a system as it is impossible to eliminate all risks but only to reduce them to an acceptable level. So, what is the acceptable safety level? One basis for judgement used in British law is that a product should be as safe as is reasonably practicable. However, that poses the question — what is reasonably practicable? It may be assumed that the whole subject of design for safety criteria depends upon the answers to three basic questions.

1. What can go wrong?
2. What are the effects and consequences?
3. How often will it happen?

The answers to these questions may change with time or the particular problem in hand. However, for M/E systems of marine products, design for safety would have the
general objectives of improvement in safety and reliability utilising technological advances. Modern methods of safety analysis enable the risks to be more easily identified and an estimation of the magnitudes to be determined more confidently. Control systems, sensors, alarm and protection systems provide the means to determine disturbance conditions and necessary actions. The criteria for M/E system design for safety of marine products can generally be described as follows:

1. Safety devices and protection systems are the principal contributors to system safety.
2. Safety devices, control systems and protection systems should be designed to have similar failure rates to the system being protected.
3. Safety devices, control systems and protection systems should be designed to fail safe with reference to the controlled system.

2.2. General framework

Design for safety should become an integral part of the design process. A model can be presented by an analysis phase, a synthesis phase and an evaluation phase. A design for safety framework based on this general methodology is proposed as shown in figure 1.

![Figure 1 Design for safety framework](image-url)

2.3. Detailed study of design for safety framework

Problem definition is very important in the analysis phase. This would include definition of objectives, identification of hazards and risks, definition of constraints and assumptions. Definition of objectives would define safety and reliability requirements and levels of maintainability and availability. Identification of hazards and risks would identify all of the possible hazards and associated reliability and safety data. Preliminary Hazard Analysis (PHA), Event Tree Analysis (ETA), Fault Hazard Analysis
(FHA), Failure Mode, Effect and Criticality Analysis (FMECA), Cause-Consequence Analysis (CCA), Fault Tree Analysis (FTA) and Safety Hazard Report (SHR) can all be used to identify possible hazards and risks. FMECA is popular with design engineers.

The synthesis phase may involve both qualitative and quantitative safety analysis. Weaknesses in design may be identified and redefined. Redundancies, protection systems and alarm systems may be used to improve the reliability and safety of a particular system. Safety techniques that may be used include Boolean Representation Method (BRM), Fault Tree Method (FTM), Markov Model (MM), Monte Carlo Method (MCM), and Simulation, etc. It must also be remembered that safety is not only determined by design but is affected by operation, maintenance, installation, construction and commissioning.

In the evaluation phase, all aspects should be considered. Reliability and safety methods may be used for a detailed analysis of the maintenance requirements.

2.4. An expert system for safety design
Expert system technology could be usefully applied to design for safety as shown in figure 2.

![Figure 2 The structure of design for a safety expert system](image)

3. SYSTEM SAFETY MODEL

3.1. Requirements for system modelling
A system safety model is an expression interrelating the logic and components that may be used to carry out qualitative analysis and numerical computation of the reliability and safety of a system. The requirements for modelling are as follows:
1. Must accommodate the level of system complexity required by design engineers,
2. Must allow reliability analysis to be carried out.
3. Be compatible with operational and logistical requirements.
4. Being compatible with other aspects of technical design.

3.2. Assumptions for modelling a safety system
Assumptions are necessary for modelling. Choosing assumptions depends on the practical requirements and analysis techniques to be used. For simplification of analysis, the following assumptions may be used.
(1). Every component is considered independent. If a system is divided into several sub-systems, every sub-system is assumed to be independent.
(2). A continuous variable may be expressed by two states or multi-states such as high, too high, normal, low and too low one of which corresponds to a certain range of operation.
(3). There is no preventative maintenance during a mission, and failed components are assumed to be repaired to new condition.
(4). The probability distribution used in reliability and safety analysis is assumed to be exponential and the repair rate is assumed to be constant.

3.3. Modelling techniques
The purpose of safety system modelling is to provide a base for qualitative and quantitative safety analysis. Modelling techniques could be BRM, FTA, simulation methods, etc. Various state-of-art techniques can be used to assist safety system modelling. Good definition and suitable assumptions are the key to the effective and efficient modelling of a system.

4. QUALITATIVE SAFETY ANALYSIS
Qualitative safety analysis is used to locate possible failures and to identify proper precautions which will reduce the frequency or consequences of such failures. A qualitative reliability and safety analysis can be performed with one or more of the following objectives.
(1). To identify weak links in design.
(2). To assess the relative importance of all identified failures.
(3). To provide a systematic assessment of overall system and subsystem safety.
(4). To provide the essential knowledge for quantitative safety analysis.

The general steps in a qualitative system reliability analysis are to:
(1). Determine failures and identify consequences.
(2). Document safety and reliability knowledge in table, or other format.
(3). Evaluate overall system safety considering the above information.

4.1. Identification of hazards
Understanding design details is very important for identifying hazards. Corresponding to every failure mode, the failure rate, effect on system and method of failure detection can be determined by FMECA. Criticality analysis can also be carried out with regard to the corresponding risk criticality category.
4.2. Qualitative reliability and safety techniques

(1). FMECA

FMECA does not do the whole job, but does provide some early answers and a firm base for later study and analysis. Once the system and its intended use are defined and understood, the actual FMECA can be performed. The complexity of safety analysis using this technique depends on the system and the experience and knowledge of analyst.

(2). Boolean representation method.

Boolean representation is a method which can be used to automate construction of minimum cut sets of a system top event. Compared with the fault tree method, this method is also more versatile. Further safety analysis can be referred to results obtained from this method. Information from a FMECA can be used to support safety analysis using this method.

(3). Fault tree

Fault tree analysis is a technique in which failures that can contribute to an undesired event are organised deductively and represented pictorially. Information developed in FMECA can be related to fault tree analysis. The use of this technique simulates the identification of possible failures and events, and fault trees can present all kinds of dependencies and common mode failures and events.

5. QUANTITATIVE ANALYSIS

The objective of quantitative analysis is to represent the system in a mathematical model, apportion the reliability and availability goals, and reconcile the calculated reliability and availability to the overall system goal. An intent of this analysis is to help the designer to minimise system complexity, to be aware of the characteristics of the components selected, particularly their capabilities with the environment and other technical design. A quantitative analysis utilises a mathematical model for system success as a function of some or all of the following, failure rates, repair rates, test intervals, mission time, system logic, and surveillance test schedule. Data quality could affect the results of the analysis.

5.1. Definition of mission

Two ways in general use for expressing mission success are the reliability and availability of safety components, protection systems and whole systems.

(1). Reliability

Reliability is the characteristics of an item expressed by the probability that it will perform a required function under stated conditions for a stated period of time. Data may not be available to give a good description of hazard rate throughout a component’s whole lifetime. During a period of middle life, the hazard rate is relatively constant. Reliability for a mission time can be calculated by the following expression.

\[ R(t) = \exp(-\lambda t) \]

(2) Availability

Availability may be considered as the fraction of the time the system is operational. It can be computed from the following formula.

Mean availability \[ Q = \frac{Up \ time}{Up \ time + Down \ time} = \frac{t}{t + \lambda \mu t} = 1 - \mu_d \]

Where \( \mu = \) average repair time and \( \mu_d = \) functional down time
5.2. Quantitative analysis
Once a mission is defined, the mathematical model generated and the input parameters prepared, the calculation is ready to start. Development of the model should anticipate the type of inputs required by a computer, and code should be suitable for the type of analysis required. The analysis can be carried out first to subsystem level, and then to system level.

5.3. Consistent check of results
After the results for safety and reliability are obtained, the following techniques are useful for reviewing a design proposal critically and credibly.

5.3.1. Sensitivity analysis
A sensitivity analysis is conducted for the purpose of determining the relative importance of the various component failure rates, test intervals or repair times on the system reliability and availability. The weak parts, weak subsystems or components can be identified and examined for credibility.

5.3.2. Comparison with prior analysis
If there are prior results available for similar designs, comparisons can be made. It should be checked whether the difference in results is credible in view of the design and input data, and whether the new design is consistent with experience or best judgement.

5.3.3. Modelling check
The errors in modelling a system cannot be eliminated but may be reduced to an acceptable level. It could be useful to make a list of model inadequacies and then evaluate them. If errors are significant and no conservative results are produced, designers should modify the model to accommodate the practical system.

6. M/E SYSTEM DATA COLLECTION PROGRAM
A brief survey of different field failure data collection systems reveals that most of the collected and analysed data seems to be inadequate. A reason for this may be that due considerations have not been given to the problem of determining the type of failure data required, and how to analyse and present the information. However, careful evaluation of available data for marine products may provide valuable information for the design and implementation of a more successful data collection system. Current data collecting programs tend to be of a specialised nature and are primarily concerned with military service, nuclear power station and space applications. Much of the data in these programs is applicable beyond these fields, and the use of these data sources will unquestionably benefit the analyst who has yet to establish a database of failure data. Actually, failure data is not static and should be collected dynamically. Powerful database and advanced data exchange techniques can also be utilised.

7. AN EXAMPLE
An hydraulic servo transmission system shown in figure 3 is studied as a test case to show how the design for safety methodology developed in this paper may be applied. This system is analysed on the basis of the process diagram supplied by the design engineer.
7.1. Analysis phase

7.1.1. Objectives and system description
The objective of this analysis is to provide assurance that the hydraulic servo transmission system will perform its functions reliably and safely. This analysis is also aimed to establish priorities of the components for attention during the design stage and provide criteria for operation and maintenance of the system.

This system is used to control the hydraulic power for the slewing, hoisting or luffing functions of a crane.

7.1.2. Constraints and assumptions
This hydraulic servo transmission system is assumed not to be operated above maximum rated pressures and capacities. A pipe or hose is not considered to be a component. No allowance for leaks from piping connections is made, and structural failure is considered as a possible failure mode of specific component. The oil used in this system is assumed compatible with all components. All maintenance activities are assumed to be expertly and properly carried out. Failure rate and repair rate are assumed to be constant. When a failure mode is defined as a major leak, this means a total leak of all fluid. All faults are assumed to be repaired immediately as soon as they are detected.

7.1.3. Risk identification
Risk identification is applied to identify potential failure modes of this hydraulic servo system and to define their effects and acquire reliability data at component level where a component is defined as a single hydraulic, electrical or electronic unit such as a pump, electric motor or servo control valve. The Reliability Block Diagram for this hydraulic servo system can be constructed and is shown in Appendix 1a. The criticality categories of risks can be identified as four types as follows:
1 A dangerous failure which could result in major damage to transmission system or crane.
2 Potential mission failure.
3 Failure resulting in loss of one or more motions.
4 A failure resulting in the erroneous activation of an audible or visual alarm.

The FMECA for these criticality categories of the hydraulic motor (component 183) is shown in Appendix 1b.

7.2. Synthesis phase

7.2.1. Criticality analysis

The first step for criticality analysis is to classify all of the failure modes of this hydraulic servo system which have criticality category 1 or 2 obtained from the complete FMECA analysis and shown in Appendix 2a.

Criticality number C can be calculated using the following formula.

\[
C = \sum_{i=1}^{N} \beta \alpha K_E K_A \lambda t
\]

Where
- \( \beta \) = conditional probability
- \( n \) = critical failure mode number
- \( \alpha \) = failure mode ratio
- \( \lambda \) = failure rate (failures per million)
- \( N \) = last critical failure mode
- \( K_A \) = operational factor
- \( K_E \) = environmental factor

For simplicity of demonstration, \( K_A \) and \( K_E \) are taken as 1. The critical number for the critical failure modes can be calculated on the basis of the FMECA and is shown in Appendix 2b. The operating time (t) is taken as 10000 hours for this analysis. The analysis shows that 12 components in this servo hydraulic system are classified as having criticality 1 and 2. Criticality analysis shows that failure modes of components 161 (pump) and 183 (motor) with criticality category 2 have criticality number 0.175, and failure modes with criticality category 1 have criticality number 0.14. The failure modes with criticality category 1 for these two components are port plate separation, shaft failure and major leak. Comparing these failure modes port plate separation has a high probability of occurrence when compared to the other failure modes and therefore should be given more attention. During the design stage, the pump (161) and motor (183) should be considered in more detail from a safety viewpoint.

7.2.2. Qualitative analysis

The severe failure modes have been identified as follows considering the pump (161) and motor (183).

1. Shaft failure
2. Major leak

The first one can easily be identified and analysed. The possibility of this failure occurring can be reduced by good maintenance, installation and provision of a quality shaft. From the final critical transition table as shown in Appendix 3 based on major leaks as a top event, it can be seen that either pump 161 or motor 183 can cause a major leak. During design, these two components have priority consideration.

7.3. Evaluation phase
7.3.1. Quantitative analysis

<1>. Reliability
Based on the critical transition table, the reliability for every cut set can be calculated for a time period of 10000 hours. The result is shown in Appendix 3.

<2>. Availability
Due to lack of relevant component repair data, it is assumed that the average repair time for every component is three hours. The availability of this system can be calculated as:

\[ Q = 1 - \sum \mu_i = 0.9988 \]

The components with high failure rates affect the magnitude of the mean availability of the system more than others. The reduction in repair time for those items with high criticality numbers would affect significantly the availability of the system.

7.3.2. Evaluation and discussion
Hydraulic systems are different to other systems because oil leakage and contaminated oil may cause many problems. Possibility of failures, caused by debris to component 161 and 183, can be reduced by fitting an oil filter. Port plate separation causing a major hydraulic leak could result in the crane load falling. This potential risk can be reduced by considering this component specifically and fitting suitable protection systems to the brake system. Other potential failures can be reduced by protection components such as 176, 166, 175 and 167 which are used for protecting against high pressure in this hydraulic system. The aspects of the maintenance can be viewed from the availability obtained. For this specific system, it would be difficult to change the design proposal. Nevertheless, engineering system design based on this proposed framework can be beneficial from a safety viewpoint.

8. CONCLUDING REMARKS
Attempts to improve the safety of marine products focus on safety components, and protection systems and the integration of design for safety into the design process. There are some strategies which can be applied in order to implement design for safety. The first is to concentrate on risk identification from a viewpoint of various potential hazards and their consequences. The second is to review all of the safety devices and the whole system, estimate all of the hazard paths and quantify them with the various available reliability techniques. The third is to reduce the possibility of risks to an acceptable level with regard to operation, installation, maintenance, etc.

Engineers designing marine products require information to design for safety. A design for safety framework has been studied in this paper. This framework is very general and may be applied to various marine systems. Practically, a design engineer would still face a great deal of difficulty, and this may only be improved by design for safety training, development of flexible safety analysis techniques and use of information man-machine interfaces for the formulation of knowledge and information.

9. ACKNOWLEDGEMENT
This work forms part of a project on design for safety supported by the UK Science and Engineering Research Council under Grant No.GR/F 95306.

10. REFERENCES
APPENDIX 1 RBD AND FMECA

a. RBD

b. FMECA

<table>
<thead>
<tr>
<th>Component name</th>
<th>Variable displacement axial piston of motor (161)</th>
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</thead>
<tbody>
<tr>
<td>Function</td>
<td>Failure mode</td>
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<tr>
<td>1</td>
<td>Change the displacement axially</td>
</tr>
<tr>
<td>2</td>
<td>Port plate separation</td>
</tr>
<tr>
<td>3</td>
<td>Motor seizure</td>
</tr>
<tr>
<td>4</td>
<td>Shaft failure</td>
</tr>
<tr>
<td>5</td>
<td>Minor leak</td>
</tr>
<tr>
<td>6</td>
<td>Major leak</td>
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APPENDIX 2a Criticality analysis, hydraulic servo transmission system

<table>
<thead>
<tr>
<th>Component No.</th>
<th>Failure mode</th>
<th>FM No.</th>
<th>FM ratio (Per million)</th>
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<td>failure to cause debris to enter circuit</td>
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<td>70.00</td>
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<tr>
<td>161</td>
<td>port plate separation causing hydraulic major leak</td>
<td>2</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>161</td>
<td>shaft fault</td>
<td>3</td>
<td>0.05</td>
<td>1</td>
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<td>161</td>
<td>major leak</td>
<td>4</td>
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<td>fail to close</td>
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<td>major leak</td>
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APPENDIX 2b Criticality number

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APPENDIX 3 Reliability analysis

The reliability of this system at 10000 hours is 0.8998
Abstract

The dynamics of ship propulsion are examined in this paper and, in particular, the ship's backing ability and its enhancement through various means. The most important aspects of ship backing are reviewed and a number of alternative methods available for the improvement of backing performance are evaluated by means of computer simulation, with particular reference to a high-speed ferry application. Results are presented for coasting stops under windmilling propeller or locked shafting conditions and the improvements possible from the application of both "soft" and "hard" brakes quantified in relation to engine stall occurrences and subsequent starting requirements. Results for CPP systems are given including potential improvements when alternative control strategies are followed. It is concluded that significant improvements in stopping time and head reach are possible through careful consideration to design details in propulsion systems hardware and control strategies.

1. Introduction

Although the stopping ability of every self-propelled ship is considered essential and "emergency crash-stop maneuvers" are conducted regularly during sea-trials, such tests are not mandatory and are mostly used to demonstrate the adequacy of design of the propulsion systems. No established criteria exist to judge the stopping ability of ships as a means of hazard-avoidance and "human factors" (such as crew negligence, communication failure, inadequate training, etc.) are often thought to be responsible for accidents. However, one must be aware of the fact that under certain conditions (heavy traffic in crowded harbours - packed with boats, barges, etc), navigation margins are markedly reduced and a closer look at the ship's stopping ability, and the means by which it can be improved is, therefore, warranted.

2. The Backing Requirements of Ships

For every self-propelled ship, the ability to stop and reverse is considered essential. The "emergency crash-stop at full-ahead speed" is common in all important ship trial codes (Landsburg, 1983), although such a test is not even considered mandatory (Coates, 1987), as it is conducted under very specific conditions, rarely encountered during pilotage (operation in restricted waters).

2.1 Backing as a Means of Maneuverability

The most obvious reason calling for a certain level of backing capacity is the requirement to maneuver the ship into a desired position such as during berthing or navigating in pilotage waters. Under such
circumstances, in the great majority of cases, the traveling speed of
the ship is well below that of full ahead and the availability,
therefore, of astern power is rarely a problem (as is the case during
crash stop from full ahead; where the hydrodynamic windmilling effect
of the propeller may lead to demands for substantial levels of power
from the prime mover). Instead, as the ship has to respond to frequent
changes of ordered speed, the time lags involved in the process of
reversing propeller thrust and the rate at which reverse power can be
built up are the predominant issues for consideration.

2.2 Backing as a Means of Accident Avoidance

It is possible for the ship to be running at full speed ahead when ship
maneuvering is initiated (to avoid a potential collision, for example).
Considering the directional instability of conventional single screw
ships with the propeller producing reverse thrust (Crane, 1973), it is
virtually impossible to avoid uncontrolled lateral path and heading
deviations during a crash-stop maneuver, unless special means of heading
control (such as use of bow or other thrusters) is provided. (In the
case study, presented thereafter, such control possibilities are
assumed.) On the other hand, if sufficient sea room is available,
turning is by far superior to stopping, for the purpose of hazard
avoidance, for most types of ships. Advance in a turn is much less than
stopping head reach, and directional control is maintained (Crane,
1973). Hence ship backing, as a means of accident avoidance, is most
important for rather modest approach speeds, while navigating in
restricted waters.

3. Systems Considerations in Relation to Ship Backing

In evaluating the backing performance of ships, it is instructive to use
ideas and methods of systems engineering. The ship system, as a whole,
can be represented as an (integrated) assembly of its various subsystems
(Bakountouzis, 1991). For the purpose of the present study, it is
sufficient to consider the ship-system consisting of: the hull, the
propulsor, the transmission and the prime mover subsystems, interacting
with each other and with additional inputs, as the case may be,
resulting from the intervention of the human operator and/or the
presence of the environment. Figure 1 shows, in a simplified way, the
various subsystems and their interactions.

3.1 Prime Mover - Backing Power Availability

In most ocean-going vessels, prime movers are directly coupled to the
propeller. As a result, engine reversal is required for the production
of reverse thrust.

3.1.1. Diesel Machinery

The turbocharged diesel engine is by far the most common type of prime
mover, nowadays. It can in general be assumed that reversible diesel
engines have nearly equal torque-speed characteristics when running in
either direction, which implies that, in principle, full power can be
made available for astern operation. At low approach speeds, the engine
will have no problems in being reversed rapidly (Crane, 1973). However,
this is not the case when the approach speed and, in addition, the ship's inertia are high, due to the windmilling effect of the propeller; the reversing process can not not be started until the engine and the propeller have coasted nearly to a stop which, for the case of a 50,000 DWT cargo ship, for example, might be of the order of 4 minutes (Schacht, 1979).

3.1.2 Turbine Machinery.

In contrast, to the diesel engine, merchant marine astern steam turbines are usually designed to provide 80% of normal ahead torque at an astern propeller speed of 50% of normal ahead speed (classification requirements). Under these conditions the stall (zero-speed) torque may be 100% of the full load torque (Clarke, 1971). [It can also be shown, theoretically, that the stall torque of a turbine is twice that at the design point (Woodward, 1975 - chapter 4).] Studies show that, for large ships, like VLCCs and ULCCs, stopping distance and time can be reduced by increasing available astern power (Crane, 1973). However, continuing increases in astern power provides diminishing returns, especially for high approach speeds (mainly due to the significant contribution of ship resistance in slowing down the ship - which is independent of the available astern power). An additional disadvantage of increased astern power would be, of course, the increased losses incurred when going ahead, with possible serious repercussions to the overall efficiency. As far as gas turbine propulsion is concerned, it is noted that these are not made reversible and employ, instead, either CPP or reversible gearing. Effectively the whole of the installed power is available for astern operation.

3.2 Propulsor - Power Absorption

During backing the flow angles to propeller blade sections can vary widely, thus making the onset of cavitation inevitable. In fact, according to Harvald (1967), any screw in reversal is in a state of extreme cavitation and, as a result, 'no-cavitation propeller' may be impossible to attain, unless the ship speed has been reduced substantially and the propeller rotation rate is very low. Since duration times under such conditions are small, erosion problems can be disregarded and the aim should be to reverse and run the propeller as fast as possible and at as high reverse power as possible, in order to achieve minimum stopping times. (Other researchers had earlier suggested, (D'Arcangelo, 1957), that there may be a possible optimum rate at which the propeller should be reversed for optimum results.) Under conditions of limited draft power absorption can be reduced significantly; propeller characteristics (and also values of propulsion factors - discussed next) should be corrected for Froude No. effects (Bakountouzis, 1992).

3.3 Hull-Propeller Interaction

While it is generally true that if more backing power is available at a faster rate the ship can be stopped faster, the backing performance of the ship depends on the condition under which the backing power is converted into reverse thrust, i.e. on the propeller characteristics and the hull-propeller interaction. In general, the higher the wake factor, the lesser the hydrodynamics load on the propeller and this can have a
favourable effect on the reversing performance of the propulsion system (Schacht, 1979). This is particularly important in single-screw, full-formed ships, where the wake factor can be of the order of 0.4 or greater. It has been suggested, furthermore, that braking flaps can be fitted on the hull (and activated as necessary to increase hull friction). Such flaps, particularly if installed at the bow, can lead to widening of the boundary layer, thus increasing the wake and permitting earlier propeller reversal. When the propeller is reversed, the flow pattern at the stern of the ship is significantly disturbed and no stable flow pattern may emerge over a certain speed range (Harvald, 1967), with some energy being expended in altering the wake pattern, thus temporarily reducing that available to affect ship stopping (D'Arcangelo, 1957).

3.4 Hull-Bottom Interaction

As has already been mentioned, the stopping performance of large ocean-going vessel is, by and large, a hydrodynamic problem. Therefore, when a vessel enters shallow or restricted waters, the stopping performance is likely to be affected. In fact, in the present context, the shallow water problem is in many ways a most relevant issue, since rapid stopping is mostly needed in ports or other areas with a restricted sea room. Unfortunately it is also a complicated situation to investigate. Stopping trials on VLCC had shown that the stopping performance is improved by the braking effect of the sea bed, although operators appear not to agree (Coates, 1987).

Theoretical studies are equally contentious. It is generally accepted that in shallow water the bare ship resistance increases (Harvald, 1983; pp. 76-78). Also, the wake and thrust deduction fractions vary considerably in different depths (Harvald, 1976). There is hardly any easily recognisable pattern in their variation, except that, in general, both increase as the depth of water decreases. Increased ship resistance, and wake fraction, tend to reduce the stopping time and head reach of a vessel while increased thrust deduction fraction tends to lead to opposite results. Different studies (Harvald, 1976; Fujino, 1990) have lead to different conclusions as to whether shallow water can improve or not ship stopping. It appears that the specific configurations of the vessels studied play an important role.

4. Evaluation of Potential Improvements in Ship's Backing Performance

For most ocean-going vessels equipped with the slow-speed, directly-coupled diesel engine, engine reversal (in conjunction with tug boat assistance in ports) has been almost universal. Controllable pitch propellers, electric transmissions, reversing gears (in conjunction with hydraulic, usually, couplings) and, more recently, reversible converter couplings have been developed in order to eliminate the need for engine reversal.

A number of alternative hydrodynamic aids (water parachutes, brake flaps, passive duct system, etc.) have been proposed for emergency stop of large ships. It seems that none of these has yet been accepted as a viable commercial proposition.
4.1 A Case Study

Early work in estimating the ship's stopping ability, as expressed by head reach and time-to-stop ship, involved the derivation of simple formulae and the production of families of curves (D'Arcangelo, 1957). The aim was to determine the required astern power to be installed on steam turbine ships. With the wide availability of digital computers and the accumulation of experimental data over the years, ship dynamics during backing can now be predicted efficiently by means of computer simulation.

For the purpose of evaluating some of the means available for the betterment of stopping performance and, also, to quantify potential improvements, a high speed coastal ferry is selected as a case study. The vessel under consideration is a twin screw (CPP), with two engines (HSD) per shaft, each providing approximately 3 MW of power at the design maximum speed.

A mathematical representation of the complete system is formulated on a functional component basis typical of similar studies (Rubis, 1972, Thompson, 1984). The complete system is divided into its functional components, such as ship hull, propeller, diesel engines, etc. (Fig.1), with the relevant characteristics of each represented by mathematical formulae or tabulated values. The diesel engine is further broken up into its functional components such as turbocharger, manifold and cylinders (Fig. 2) and each represented by suitable formulae or tabulated values (Woodward, 1984).

4.1.1 Limiting Conditions

It is instructive to consider limiting conditions in backing performance first. Figure 3 shows results for ship speed and head reach under coasting (ie. ship stopping without the application of reverse power - which could also be taken as failure to start the engine), windmilling conditions. This, obviously, represents the worst possible scenario. Figure 4 shows results under coasting conditions again, but this time with the shaft arrested immediately after the fuel is cut-off. It is seen that a "locked" propeller contributes significantly to the total hydrodynamic drag of the ship. (In both cases, as can be seen in the figures, the ship is considered "stopped" when the speed is reduced to one knot.)

Figure 5 shows results for the other extreme condition; that of an idealised stop, where the full-load engine power is available at all times following the initiation of the maneuver. This, theoretical possibility, would only be possible for a CPP installation, where the pitch is constantly updated in order to ensure maximum power absorption. It is noted that for this (hypothetical) case, the value of the maximum thrust produced is more than three times that of the design speed.

4.1.2 Wake Effects

There is a pronounced lack of data for the values of the propulsion factors (and also propeller cavitation) under backing ship conditions. Some studies disregard their effect altogether (Miniovich, 1958),
whereas others have suggested the use of behind-the-hull propeller data (Rubis, 1978). In this study a number of different scenarios for the values of the wake during backing have been assumed, in order to evaluate its effect on the results obtained in the preceding section. These scenarios included constant values for the wake, plus combinations of constant and speed-dependent terms, the relevant figures deduced from Harvald (1967, fig. 20). It was found that, for this particular, twin-screw application, the maximum variation in stopping times was no more than 4%, only. Wake effects were subsequently disregarded in all other calculations.

4.1.3 Shaft Brakes

Figure 6 shows simulation results from the application of a "soft" brake and figure 7 corresponding results from the use of "hard" brake. It is seen that the "hard" brake reduces the shaft speed to zero more quickly which leads to significant improvements in total time to stop and head reach. However, it can also be seen in figure 7 that repeated starting is needed in the case of the hard brake, as the engine is unable to provide the torque demanded and subsequently stall occurs. It is evident, therefore, that some sensing devices need to be incorporated in order to avoid unnecessary starts and loss of starting air. For both simulations open-loop linear fuel rack control is assumed, at a rate of 3% per second (as can be seen in the figures). Faster fuel rates do not show any serious improvements due to limitations imposed by turbocharger surging.

4.1.4 Controllable Pitch Propeller

During a crash stop maneuver, the steady-state combinator control of the demanded pitch and speed are discarded (Forrest, 1972, Newmann, 1984, Fowler, 1987). A typical control strategy is shown in Fig. 8 (Forrest, 1972). As seen, the demanded speed is reduced to idling while the pitch decreases at a constant, maximum rate. Speed is increased to maximum when the pitch becomes negative. Figure 9 shows computer simulation results for some of the major system parameters for the case study ship. It can be seen that sudden load is imposed on the diesel engine after the pitch changeover from positive to negative; the engine is stalled and its speed (and power) can only recover slowly. The end effect is increased stopping time and head reach.

Figure 10 shows an alternative control strategy. To take advantage of the increased load acceptance ability of the diesel engine at higher speeds, the demanded speed is raised slightly ahead of the pitch changeover point. It can be seen (Figure 11) that the engine can now recover more quickly, as compared with the previous schedule. Stopping time and head reach are shown to be decreased by 21% and 11% respectively.

5. Conclusions

There are no established criteria to judge the adequacy of the ship's stopping ability. Backing as a means of maneuverability as well as a means of hazard avoidance needs to be considered.

The means and methods available for the improvement of the stopping
ability of ships have been examined by following a systems approach with consideration being given to the major ship subsystems and their interactions. Potential improvements have been evaluated through computer simulation with reference to a particular ship application. Results indicate that significant improvements in stopping times and heads reached are possible, although careful consideration to design details in propulsion systems hardware and the control strategies pursued might be required.

Acknowledgments

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Fig. 1 Ship Subsystems

Fig. 2 Engine Subsystems

Fig. 3 Windmilling Stop
Fig. 4 Arrested-Shaft Stop

Fig. 5 Idealised Stop

Fig. 6 Soft Brake (Open Loop Fuel Control - 3%/sec)
Fig. 7 Hard Brake (Open Loop Fuel Control - 3%/sec)

Fig. 8
Pitch/RPM Schedule
[Forrest, 1972]

Fig. 9 Ship Simulation Results (Schedule Fig. 8)
Fig. 10 Revised Pitch/RPM Schedule

Fig. 11 Ship Simulation Results (Schedule Fig. 10)
Abstract

As environmental regulations are becoming more stringent, emissions of (marine) diesel engines have to be dealt with. So far the use of primary measures, engine modifications, can not meet the governmental requirements. Therefore secondary measures, 'post combustion control' or 'end of the pipe solutions', come into view. At Delft University of Technology a catalytic process to remove soot and NO\textsubscript{x} simultaneously is under development; soot will be oxidized to CO\textsubscript{2} and NO\textsubscript{x} will be converted into N\textsubscript{2}. A two stage process is used: a soot oxidizing step with in series a NO\textsubscript{x} conversion system. The first step consists of a catalytic soot converter. The emphasis of the research in this field lies on the development of a suitable catalytic material. To remove NO\textsubscript{x} from the exhaust gases an aqueous urea solution is injected. The research focuses on the implications of using urea as well as on catalyst improvement for the specific use in diesel exhaust gases.

Introduction

Environmental issues are becoming increasingly important. Legislation is pressing on to reduce any emission causing water, air or soil pollution. In this case, the diesel engine, the primary concern is air pollution. Reduction strategies can be divided in primary and secondary measures; preventing and abating emissions. The first group can be subdivided in engine and fuel modifications. This paper can be categorised in the second group; the 'end of the pipe' solutions. The kind of reduction strategy to be applied depends mainly on the kind of pollution to be reduced. A summary of the relevant pollutants will follow and subsequently the diesel engine emissions will be discussed:
Carbon dioxide (CO₂) is the main pollutant present in the diesel exhaust gas. This product is unavoidable when burning fossil fuels and the only reduction strategy is using as little fuel as possible; an efficient engine.

Sulfur oxide (SOₓ) formation is proportional to the sulfur content of the fuel used. The only sensible way to reduce this emission appears to be applying low sulfur fuels.

The main part of the nitrogen oxides (NOₓ) emission is caused by thermal oxidation of nitrogen in the air. It is possible to reduce this NOₓ emission by lowering the combustion temperature, generally causing a decrease in combustion efficiency. Moderate (50%) reductions can be obtained by engine modification at the cost of a considerable fuel penalty. It is expected that substantial reductions (>80%) can only be obtained by secondary measures.

Emission of unburned hydrocarbons (HC) results from low combustion efficiency and/or poor fuel quality. Carbon monoxide (CO) emission results from poor combustion. A high combustion temperature will reduce both emissions.

The emission of ash, soot and sulphates etc, generally referred to as particulates completes the picture. This emission is caused by the fuel and lubricating oil (sulphates & inorganic materials), the engine itself (some metals) and a poor combustion (soot).

It is noted that some emissions are correlated; lowering NOₓ emission by decreasing the combustion temperatures can cause a considerable increase in CO/HC & soot emission. This type of complications are giving engine manufacturers only a narrow margin for engine modifications.

**Diesel & otto engines**

Compared with other type of engines (the otto engine, figure 1) the diesel engine has a low CO/HC emission as a result of the high combustion efficiency, a moderate NOₓ emission and a relatively high particulate emission. The goal of the research is to lower the NOₓ and particulate emission by post combustion control. The temperature of the exhaust gases is relatively low (200-600°C), so a catalyst has to be applied. For otto engines three-way catalysts are extensively used. However these catalysts...
can not be used for diesel engines, the reason is obvious:
According to the name of the catalyst three reactions take place. The unburned hydrocarbons and CO are oxidized to CO₂ and water;

\[
\text{CO} + \frac{1}{2} \text{O}_2 \rightarrow \text{CO}_2 \quad (1)
\]

\[
\text{HC} + \text{O}_2 \rightarrow \text{H}_2\text{O} + \text{CO}_2 \quad (2)
\]

After almost complete oxygen conversion the reduction of NOₓ can take place;

\[
\text{NO} + \text{CO} \rightarrow \frac{1}{2} \text{N}_2 + \text{CO}_2 \quad (3)
\]

Because of these contradictory requirements, oxidation and reduction, the reactions depend strongly on the conditions of the exhaust gases. This boils down to a strict demand on the air-fuel ratio, which has to be about stoichiometric (figure 2); this is controlled by the so called λ-sonde. However, a diesel engine operates with an air excess; the exhaust gases always contain at least a few percent of oxygen. This prevents reaction 3 taking place because there are no reducing agents present any more. Fur-
thermore some modern diesel engines produce not enough CO and HC for all the NO\textsubscript{x} to be reduced at all.

The DUT approach

Essentially the oxidizable part of the particulates have to be oxidized to H\textsubscript{2}O and CO\textsubscript{2} and the NO\textsubscript{x} converted to N\textsubscript{2} and H\textsubscript{2}O. For the oxidation of the particulates a promising technique is catalytic oxidation because the temperature is too low for spontaneous oxidation to occur. The main focus of the research lies on developing a suitable catalytic active material. For the reduction of NO\textsubscript{x} catalysts are available in similar applications (reduction of NO\textsubscript{x} in electric power plants). A reducing agent has to be added; normally ammonia (NH\textsubscript{3}) is used. Applying this technique on diesel engines (or other relative small scale O\textsubscript{2} rich gases like lean-burn gas engines) NH\textsubscript{3} is difficult to use for safety reason. Therefore an aqueous solution of urea is used. This type of process is already extensively investigated in the Delft group for the removal of NO\textsubscript{x} from gas engine off-gases (Wypkema, 1991). Further catalysts, especially for diesel engine application, are under development.

Soot removal

The first step in developing soot oxidation catalysts is the characterization of soot (particulates). In figure 3 a schematic representation of a soot particle is given, using 0.3 wt % sulphur containing fuel. The composition of soot depends on the fuel composition, type of engine used, general engine conditions, sampling conditions, etc. The core of a soot particle is a carbon nucleus surrounded by adsorbed inorganic salts and hydrocarbons. The graphite like carbon nucleus is rather unreactive implying strong demands on the activity of the catalyst.
Present soot removal systems consist of (catalytic) filters which are periodically cleaned by externally heating. Since these systems have serious drawbacks, flow-through monoliths (figure 4), equipped with a good soot oxidation catalyst are considered to be a better choice (Saito, 1991). An important reason is that plugging due to incomplete or failed regeneration does not occur and a small pressure drop is maintained. (A monolith consists out of a large number of parallel channels, coated with catalytic material. The main advantage of this configuration is the relative low pressure drop and the relatively high resistance to dust loading.)

A suitable catalytic material has to be developed. One of the results is that, besides the chemical composition of the catalyst, the contact between soot and catalyst is crucial for the catalytic activity. An extra demand of the catalyst is a relative low SO$_2$ oxidation rate. Good oxidizing catalysts, such as Platina, tend to oxidize SO$_2$ to SO$_3$ causing all kinds of corrosion and salt deposition problems to occur. The so formed sulphates will be leaving, at least partly, the system as particulate material. So using an oxidizing catalyst may increase the particulate emission, the carboneous structures replaced by sulphates.

**Marine diesel engines**

As already stated the particulate composition depends on the type of fuel used. Heavy fuel oil generally contains up to 3 wt % sulphur. The resulting particulates may contain over 50 wt % sulphates/inorganic oxides (Götmalm, 1991). These compounds cannot be removed by oxidation. As a result, the theoretical particulate emission reduction for oxidation is limited to this 50 percent. The only solution is using low sulphur fuel oils. The resulting particulates will contain mainly oxidizable structures and catalytic oxidation can achieve a considerable decrease in emission.
NO\textsubscript{x} removal

For the reduction of NO\textsubscript{x} in the presence of oxygen there is a sound technological basis available. Over 90 GW (Ribeiro, 1990) of coal-fired power plants (mainly in Japan and Germany) have been equipped with SCR technology. SCR stands for selective catalytic reduction of NO\textsubscript{x}. The point being that diesel operates with oxygen excess; so an agent has to be added which can selectively remove NO\textsubscript{x}. For this purpose ammonia (NH\textsubscript{3}) is used;

\begin{align}
4 \text{NO} + 4 \text{NH}_3 + \text{O}_2 &\rightarrow 4 \text{N}_2 + 6 \text{H}_2\text{O} \\
6 \text{NO}_2 + 8 \text{NH}_3 &\rightarrow 7 \text{N}_2 + 12 \text{H}_2\text{O}
\end{align}

(4) (5)

Ideally, the only products are nitrogen and water. Ammonia is injected into the exhaust gas at a temperature of 300-400°C and subsequently the gas mixture is passed through a catalyst bed. The degree of NO\textsubscript{x} removal depends on the amount of ammonia added; however, an increase in added ammonia can result in higher levels of ammonia in the cleaned flue gas (NH\textsubscript{3} slip). This concentration of NH\textsubscript{3} should be as low as possible because NH\textsubscript{3} forms salts with SO\textsubscript{3} which will condensate at lower temperatures, thereby deactivating the catalyst or causing problems in the exhaust gas system. For fuels containing large amounts of sulphur this means a lower temperature limit for the operation of the catalyst of about 300°C. The upper temperature limit, 400°C, is determined by the catalyst stability, increased NH\textsubscript{3} oxidation and excess SO\textsubscript{2} oxidation.

A serious drawback of applying this technique on a relative small scale is the use of NH\textsubscript{3}. Ammonia is a poisonous and combustible gas which has to be stored as a pressurized liquid. So for safety reasons the use of NH\textsubscript{3} is not recommendable (and often even not allowed by unskilled persons). Therefore NH\textsubscript{3} has been replaced by a harmless substituent; urea. Instead of ammonia a 40 wt % aqueous urea solution can be injected. This type of process is already extensively investigated in the Delft group for the removal of NO\textsubscript{x} from gas engine off-gases in order to use their CO\textsubscript{2}-content in greenhouses for crop growth stimulation (Wypkema, 1991).

This process has been tested with the exhaust gases of a real gas engine. The same type of process can be applied to the exhaust gases of diesel engines (demonstrated by Held, 1990). The research in this field can be divided in two areas, firstly the catalyst development and secondly the implications of using urea.
Catalyst development

The catalysts currently used are mostly of the flow-through-monolith type and consist of an extrudate of vanadium pentoxide on a titanium dioxide carrier. Several additives are used to improve the performance. Most of these catalysts are applied with (steady state) electric power installations. This means that the catalyst condition (temperature) is essentially constant. The temperature range in which the catalysts are used is 250-400°C.

For diesel engines this temperature range is rather small; at low loads the minimal temperature will not be reached. The low temperature limit is determined by the lack of activity of the catalyst on the one hand but more important depends on the sulphur content of the fuel used. At temperatures above 400°C the catalyst starts oxidizing SO₂ and NH₃ giving rise to particulates and NOₓ emission. At still higher temperatures (>500°C) the catalyst is not stable any more and will deactivate irreversibly.

Therefore the catalyst development is aimed at searching for catalysts which can also be used at higher temperatures and do not oxidize NH₃ and SO₂. Furthermore improvement of the activity of the catalyst is of importance. At this moment the focus of attention is on metal exchanged zeolite type catalysts (silicium aluminates with a relatively high thermostability). These catalysts are being synthesized and tested in lab scale facilities.

Urea

Granular urea is widely used as a fertilizer. It dissolves rather good in water, up to 50 wt % at 20°C, the solution being clear and odourless. The solution, 40 wt % urea in water, is injected in the exhaust gas stream using an atomizer (preferentially a twin media nozzle with regard to plugging problems). Subsequently, urea decomposes, mainly and simplified, according to:

\[ \text{CO(NH}_2\text{)}_2 + \text{H}_2\text{O} \rightarrow 2 \text{NH}_3 + \text{CO}_2 \]  

A complication is that at low temperatures urea will not totally decompose but form condensation products. This means a low temperature limit for the use of urea. To be on the safe side the injection should be started above 330°C according to the decomposition temperature of cyanuric acid (one of the heaviest possible byproducts). This exceeds the
lower temperature limit of the catalyst (ammonium sulphate formation). Preliminary lab and pilot-scale experiments did not show any detectable byproduct formation above 300°C.

System configuration

The overall NO\textsubscript{x} reduction to be obtained with a SCR system depends on the configuration. Using more catalyst gives a better NO\textsubscript{x} reduction resulting in increased costs. Using more urea gives the same result, but the NH\textsubscript{3} emission (formed by reaction 6) will increase. The final NH\textsubscript{3} emission should be kept minimal (p.e. < 20 ppm). There are several solutions to deal with this problem;

Firstly one can inject a slight excess urea and subsequently oxidize all superfluous urea. The main drawback is that an extra oxidizing catalyst is needed. Furthermore most of the urea, or ammonia, will be converted to NO\textsubscript{x}. An advantage is oxidation of unburned HC, CO and some of the particulates. Secondly the outgoing NO\textsubscript{x} concentration can be measured subsequently using feedback control to regulate the urea dosage. Provided there is enough catalyst a high reduction level can be obtained. The main drawback is the difficult process control caused by the slow catalyst response. Further the mixing of urea with the exhaust gases should be rather good before entering the catalyst system.

The first system is somewhat more insensitive to the urea dosing rate. The amount of urea to be injected at a certain engine load can be obtained by mapping the engine during start-up/service. For the second system this is not sufficient to obtain a high reduction level, one needs to know what the outgoing NO\textsubscript{x} concentration is. Until now NO\textsubscript{x} measuring devices are expensive and difficult to use. At the Delft University research is being done on the development of Nernst-type NO\textsubscript{x} sensors (Ningling, 1991). These sensors are relative cheap and the principle of using them is analogous to the three-way catalyst control system. In the latter case one regulates the fuel injection with the oxygen concentration measured by an O\textsubscript{2} sensor. In the former case the urea injection can be controlled with the NO\textsubscript{x} concentration measured by a NO\textsubscript{x} sensor (when sufficiently developed).

Marine diesel engine

As already mentioned SCR is widely applied for NO\textsubscript{x} reduction. With respect to marine diesel engines two Danish engineering firms have already incorporated a SCR system using standard catalysts and ammonia
for NO\textsubscript{x} reduction in two ships. A 90 % NO\textsubscript{x} reduction is claimed cleaning the off-gases of an 8 MW two-stroke diesel engine (Gibson, 1991). A similar system using urea is proposed by Götmalm (1991).

**Conclusion**

NO\textsubscript{x} and particulates emission of diesel engines can be reduced using a combination of two reactors:

- flow through monolith coated with a suitable catalytic material
- monolith in which NO\textsubscript{x} is selectively removed using urea

With respect to marine diesel engines the catalytic oxidation of particulates is seriously restricted by the high sulphur content of the fuel.

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Abstract

Under the R & D Project "Diesel Concept" it was possible to achieve emissions levels far below the current "TA-Luft" limits. With a stationary direct injection diesel engine.

Through extensive basic investigations it was demonstrated, that the targets

\[
\begin{align*}
\text{NO}_X &= 500 \text{ instead of } 2000 \text{ respectively } 4000 \text{ mg/m}^3 \text{ (5 } \% \text{ O}_2 \\
\text{Particles} &= 50 \text{ (5) instead of } 130 \text{ mg/m}^3 \text{ (5 } \% \text{ O}_2 )
\end{align*}
\]

corresponding to the progressively decreasing limits clause of the "TA-Luft" could be achieved with the following modifications:

• Exhaust gas treatment through particle filter and regeneration
• Partial recirculation of the treated exhaust into the intake air
• Pressure charging of the air/exhaust mixture
• Intercooling
• Optimising engine internals
• Development a special control strategies.

Having proved the viability of the "Diesel Concept" on a research engine, the necessary endurance tests with a serial DEUTZ MWM TBD 234 V8 engine are carried out at the present.
"Diesel Engines 2000 plus"! Let us risk a glance into future.

The population will increase: from 1950 until today, we have registered almost a doubling to nearly 5 billion people. In the year 2000, there will be over 6 billion, in 2010, more than 7 billion world inhabitants.

Trading volume, and with it freight traffic, will grow as the population increases. According to investigations by the German Institute for Economic Policy, Karlsruhe, freight traffic will increase by 40-50% between 1985 and 2000, and will have doubled by the year 2010.

Almost 90% of this freight flow today is moved by diesel engines: by trucks, trains and ships. And the diesel engine will surely maintain this share, even if the requirement for prime movers increases, because there is no feasible alternative to the Diesel, either today or in the foreseeable future.

The alternatives: Gas turbines or electric drives are not competitive. The gas turbine is more than twice as expensive to produce, and has a considerably higher fuel consumption throughout the load range. The steam turbine is even worse. (Figure 1)

Grid derived electrical energy for electric locomotives compares very badly to the diesel locomotive, due to the efficiency and cost chain:

- power station
- distribution network
- electric motor.

Apart from the limited hydro electric power (approximately 5% of Europe's current energy needs), only atomic power stations can be considered to be environment friendly in the "emission sense", however they have other environment problems.

Stored electrical energy and energy derived from the sun are only worth considering for small, limited power requirements and are also appallingly low in efficiency: electro 15%, sun 5% and of high costs.

Because road traffic is already stretched to its limits, passengers and freight will be increasingly transported by rail and waterways. But locomotive and ship prime movers are also dominated by diesel engines.
The food supply requirements for the increasing population will also not be achievable through human and animal power alone. Rather, tractors and farm machinery will be needed, and these are already powered exclusively by diesels. Also, the vegetable oils that agriculture will possibly produce for its own needs (especially in the 3rd world), can only be used in diesel engines.

Why then the dispute over the diesel's right to exist? The economic forecasts are encouraging, fears of the competition are unwarranted, and the development potential of the diesel is still considerable!

And the disadvantages: exhaust smoke, noise and smell? First of all, all heat engines emit exhaust and noise - and where there is light there is always shadow. (Figure 2)

On the light, the bright side of the diesel engine are the advantages:

- economy - low fuel consumption, easy maintenance
- mobility
- modular matching to power requirement
- high, economical part load capacity
- widely used and, therefore, familiar, simple to operate and to maintain
- multi-fuel capability

On the dark side, the disadvantages are:

- harmful emissions - gaseous and particulate
- intermittent working processes - oscillations, vibrations, empty hub losses
- noise emissions
To keep the diesel engine in position, the disadvantages will have to be overcome, and the advantages improved upon - to which end engineers are working intensively and successfully: the drive for perfection is deep rooted in the soul of the creative being; in craftsmen, in artists, in philosophers and also in diesel engineers.

With this in mind, I come to the subject of my presentation: A positive contribution of our company to the negative, the dark side of the Diesel: Nitrogen oxide and soot in its exhaust gas.

This is dealt with by a "Research and Development Concept for optimised emissions reductions in diesel prime movers, specifically particulates and oxides of nitrogen". (Figure 3)

Oxides of nitrogen (NOx) and particulates (soot) count as the most dangerous emissions in diesel exhaust, and are therefore subject to the most stringent regulations, e.g. the German Clean Air Act (TA Luft) exempli gratia for stationary installations, and EURO I and II limits for trucks.

This research, which had a sponsorship of 3 million DM from the German Ministry for Research and Technology - an equal sum has also been invested by DEUTZ MWM - is based upon the fact that oxides of nitrogen and particulates (soot) react opposingly to internal engines parameters, such as injection timing changes, changes to the compression ratio, ignition delay, injection pressure, combustion period, intake air swirl as well as combustion chamber form. These relationships have been proved by us and others. (Figure 4)

An additional fact concerning soot formation, which plays a role in our considerations, goes back to Boşjakowić. Through non-engines flame tests, in 1956, he had already defined the critical air coefficient $\lambda$ for soot free combustion for common fuels. (Figure 5)

NOx originates from increasing process temperatures (Figure 8). For direct injection diesel engines, the peak temperatures at the flame front are the significant factor. Countermeasures include any avoidance of high peak temperatures, as with pre-chamber operation or, as we know from Mühlberg's tests with alcohol-diesel engines in the 1950's, by use of exhaust gas recirculations (EGR).
The effect of EGR is based on the enrichment of the intake air with nitrogen (N₂) and the partial replacement of the oxygen (O₂) with the non-reactive combustion product carbon dioxide (CO₂).

**Figure 6** shows the principle of operation. For the same charge air quantity, the oxygen content is reduced to such a level that there is just enough for complete combustion. In test engines, the excess air coefficient based on oxygen content is about 1.1 with EGR and 2.1 without EGR.

With this oxygen-lean mixture, the burning flame quasi has to thread its way around the CO₂ and NO₂ - molecules through the combustion chamber to reach the reactive oxygen.

As a result, an intense heat exchange takes place between the burning gas and the non-reactants. This in turn leads to a significant reduction in the peak temperatures as compared to combustion with fresh air.

As a three atom gas, CO₂ has a significantly higher specific heat capacity than the two-atom gases; therefore it absorbs in addition a large quantity of heat from the flame. It should now be apparent why the coldest possible, i.e. cooled, exhaust gas must be recirculated to achieve maximum NOx reductions.

The differences between partial heat release in the combustion chamber with and without EGR can be seen qualitatively in **Figure 7**. Without EGR, all of the injected fuel burns in tightly confined areas of the combustion chamber, in which, due to the high air ratio, enough oxygen is available for combustion. The combustion energy heats these gas pockets to very high peak temperatures which are then cooled to mean combustion chamber temperature through mixing with the cold unused combustion air. Conversely, with EGR, nearly all of the uniformly distributed oxygen has to be used for combustion, which results in a continuous temperature mixing process, without overheating.

This different temperature characteristic is of decisive importance for NOx formation, which increases exponentially with increasing temperature. (**Figure 8**)

With the help of this simplified illustration, I hope that I have been able to make the principles of operation of EGR understandable.
Unfortunately, the trade-off between NOx and soot formation is unavoidable also by EGR. Rather, the reduction of the excess air coefficient tends to increase in soot formation during combustion.

Exhaust gas turbocharging with charge air cooling offers one possibility to counter this trade-off. As you know, by this method, the air/fuel ratio can be increased without significantly increasing combustion chamber peak temperatures.

Figure 9 shows the direct effect of different pressure charging level. The upper curve applies to the turbocharger matched for a production engine without EGR and with optimum turbine efficiency. The lower curve is for the highest achievable boost pressure for a single stage system, whilst accepting losses in efficiency.

If we draw in figure 9 the current limits for the Clean Air Act (TA Luft), these limits were already discussed in the beginning of the 1980’s, when we first started thinking about the diesel concept, then you can envisage the dilemma of the researchers and engineers who had the theories, but lacked the reliable self regenerating particle filters and manufacturable single stage turbochargers with high pressure ratios with which to put them into practice.

On reflection, it is understandable why, rather than challenge the fundamental problem of the NOx/soot trade-off, one turned to the reduction of NOx in the Otto-gas-engine through homogeneous mixture pressure charging. With these engines, the homogeneous mixing of fuel and combustion air necessary for soot prevention takes place outside the engine and therefore is more easily achieved and controlled. This homogeneous mixture preparation is the reason why these engines have soot-free combustion.

Unfortunately, it is a widespread misconception that the use of natural gas or gasoline alone leads to soot-free combustion. The claim that natural gas is a clean fuel is in matter of fact, false. It has been known, at least since Bosjaković, that the λ Kr for this fuel is not zero. (Figure 5)

After all, the soot needed for the production of tyres is made of methane (natural gas). Equally, the fact that the λ Kr for gasoline and diesel are nearly the same does not explain why otto engines run soot-free and diesel engines produce soot. Even continuously operating burners (oil heating, jet
engines), in which liquid fuel is converted into a spray before combustion, can be run so that high levels of soot are emitted from the exhaust (start phase).

With increasing experience and the consolidation of homogeneous lean burn pressure charging, which after years of experience is now well under control in DEUTZ MWM engines with swept volumes of up to 12 l/cylinder, and relying on the availability of usable particle filters and turbocharger developments, we have once again returned to the diesel concept. In order to realise this, we have kept as close as possible to the homogeneous lean burn gas-engine system. (Figure 10)

To do this, only the particle filter PF and exhaust gas cooler AK had to be integrated. The actual load is measured by a transmitter at the injection pump instead of the throttle-valve. In the first instance, the tests were carried out on a single cylinder version of the 234 engine type, 128 mm bore, 140 mm stroke, and included an early optimisation of

a) the injection system (Figure 11), start of injection, duration, and pilot injection

b) the swirl ratio (Figure 12),

c) the combustion chamber (Figure 13),

to meet the specific requirements of the exhaust gas recirculation.

Afterwards, the work was continued on a full TBD 234 V8 engine, of which Figure 14 shows a cross-section. The first step was then to investigate the effect of boost pressure and cooling the recirculated exhaust gases. To this end, fixed and variable geometry turbochargers from KKK were used. (Figures 15 + 16)

The particle filter system DPFS, developed by KHD/DEUTZ MOTOR, was applied. This system makes use of a ceramic monolith filter element which is thermally regenerated by a special DLR burner system. The function of this filter is shown in Figure 17, the effectiveness in combination with the 8 cylinder 234 is shown in Figure 18.

With NO\textsubscript{x} level maintained at a constant 0.5 g/m\textsuperscript{3}, Bosch smoke levels (RW), i.e. soot content, can be maintained at close to up to BMEP's of 18 bar.
Further, this Figure shows that the unburnt hydrocarbon emissions (HC) can be kept below the limit of 0.15 g/norm m³ (5% O₂). Above pe = 9 bar however, the carbon monoxide content (CO) exceeds the Clean Air Act (TA Luft) limit of 0.65 g/m³. By using an oxidation catalyst, the CO limit can be achieved up to a BMEP of 16 bar without an NOₓ increase above 0.5 g/m³ (Figure 19).

In order to be able to achieve the (dynamic clause) particle limit of 0.05 g/m³, a soot filter separation efficiency of 90% is necessary. Furthermore, the oxidation of the sulphur oxides to sulphates has to be avoided, otherwise they would be measured as particulates.

Best of all is the use of low sulphur fuel, but oxidation catalysts with lower sulphur oxidation are in development.

Summing up, the diesel concept presented here, consists of the following components: (Figure 10)

- cleaning of the exhaust gas by particle filter
- cooling an amount of the cleaned exhaust gas
- controlled recirculation of this exhaust gas into the intake air (up to 50% of the charge)
- increase of the charge air pressure by turbocharger
- intercooling of the charge air
- optimisation of internal engine parameters.

Through this process, it has been possible, for the first time, to achieve the NOₓ limits of the Clean Air Act (TA Luft), of 0.5 g/m³ with a direct injection diesel engine and still maintain the significant Diesel efficiency benefits over Otto-engines. And this without having to resort to the complication of SCR technology with ammonia injection or others into the exhaust.

Figure 20 further shows the EURO II emissions limits which will become valid for truck engines from 1995. The 7 g NOₓ/kWhr (± 2500 mg NOₓ/m³) limit, which is based upon a combined 13 mode test over the entire load
range, is still far away from the 1991 Clean Air Act (TA Luft) limits which have to be complied with under full load conditions.

And this by a factor of 2.5 compared with the 1991 limit (1000 mg NO\textsubscript{x}/m\textsuperscript{3}) and a factor of 5 compared to limit for gas engines (500 mg NO\textsubscript{x}/m\textsuperscript{3}).

This comparison also shows the great development step that have been achieved with the diesel concept in improving exhaust gas quality. The technology developed on the test engine will be endurance tested to prove reliability, durability and repeatability. The last two figures show (figures 20, 21), that despite the complicate function the arrangement of the engine is rather simple. We think that within two or three years, we will bring the first "Diesel-Concept" engines on the market.

Ladies and Gentlemen,

in my presentation, I have tried to report on the results of a research project that serves the general use and advancement of the diesel engine. I hope that I have found your interest.

Thank you for your attention.
**Diesel - Engine**

**advantages**
- Economy: low fuel consumption, easy maintenance
- Mobility
- Modular matching to power requirement
- High, economical part load capacity
- Widely used and, therefore, familiar, simple to operate and to maintain
- Multi-fuel capability

**disadvantages**
- Harmful emission - gaseous and particulate
- Intermittent working processes - oscillations, vibrations, empty hub losses.
- Noise emissions

Fig. 1

![Graph showing fuel consumption for Gasturbine and Diesel engine](image)

**Fig. 2**
Verbrennungstechnik hungs- und Entwicklungskonzept zur Schadstoffminimierung
ieselmotorischen Antrieben, speziell der Stickoxid- und Partikelemission

**Fig. 3**

\[
\text{NO}_x \quad \text{mg/m}^3(5\% O_2)
\]

0% EGR

10% EGR

20% EGR

21 cm²

27 cm²

Turbine throat area

**Fig. 4**

Particle mg/m³(5% O₂)
Acetylene \( \text{C}_2\text{H}_2 \) \( \chi_{Kr} = 0.4 \)
Gasöl, Diesel fuel \( \text{CH}_4 \) \( \chi = 0.33 \)
Benzin, Gasoline \( \text{C}_2\text{H}_5\text{OH} \) \( \chi = 0.25 \)
Methane \( \text{C}_2\text{H}_2 \)
Ethanol \( \text{CH}_4 \)
Wassergas, Water gas \( 0.5 \text{H}_2 + 0.5 \text{CO} \) = 0

Fig. 5

\[ \text{fuel} \quad \text{engine without EGR} \quad \lambda = 2.1 \quad \text{engine with EGR} \quad \lambda = 1.1 \]

Fig. 6
Figure 7

Temperature without EGR

Figure 8

Equilibrium constant:

\[ K = \frac{N_2}{O_2} \]

\[ \frac{1}{K} \times 10^5 \]

Temperature vs. Time

Figure 8
Homogeneous lean burn pressure charging of 4 stroke Otto gas engines

ATL Exhaust gas turbocharger
DK Throttle valve
GLM Gas air mixer
GV Gas valve
LK Charge cooler
LS Lambda pick up
RE Control unit

Diesel concept

ATL Exhaust gas turbocharger
EP Fuel injection pump
GLM Gas air mixer
GV Gas valve
AK Exhaust gas cooler
LK Charge cooler
LS Lambda pick up
PF Particle filter
RE Control unit
1-Cyl.- TBD 234
Diesel concept
H/B = 140/128

Increased boost pressure

- Normal injection
- Normal injection
- Pilot injection

Fig. 11 Rate of exhaust gas recirculation

Fig. 12
TBD 234
Diesel concept
H/B = 140/128

- φ 67-Bowl, 4 hole nozzle, d = 1200
  Version I

- φ 80-Bowl, 5 hole nozzle, d = 1000
  Version II

- φ 13-Plunger, VH = 2,8, swirl 2,16

Cross-section TBD 234

Fig. 13

Fig. 14
8 - Cyl. - TBD 234

Diesel concept

"27er" Turbine without EGR cooling
"27er" Turbine with EGR cooling
"27er" Turbine with EGR cooling

Fig. 15 be

NOx = 0.5 \text{ g/m}^3

AGR

8 - Cyl. - TBD 234

Diesel concept

with variable turbine geometry

n_H = 1500 \text{ min}^{-1}
P_{me} = 14 \text{ bar}
The new Deutz in-line full-flow monofilter system

Fig. 17

8-Cyl-TBD 234
Diesel concept

\[ n_M = 1500 \text{ min}^{-1} \]

\[ \text{EGR Function for } \frac{\text{NO}_x}{\text{m}^3} = 0.5 \]

\[ \text{TC with "21" Turbine} \]
\[ \text{TC with VTG} \]

% EGR

Regelfunktion

\[ \text{CO} \]

\[ \text{CO Limit: } 0.65 \text{ g} \]

\[ \text{HC Limit: } 0.15 \text{ g} \]

\[ P_z \]

\[ \text{Bosch} \]

\[ \text{RW} \]

\[ \frac{\text{g}}{\text{kWh}} \]

\[ \text{be} \]

\[ \text{density} \]

\[ \lambda \text{w(CO}_2\text{)} \]

\[ \text{Fig. 18} \]

0 10 20

bar

610
CO-Limiting curve in mg/m³ (5% O₂) with oxycat, 80% conversion rate.

Fig. 19

NOx
3000

Schweiz, Schweden 91
USA 88 (60/48 hph)

Euro I/92
7-

Euro II/95
USA 91/94 (55/hph)

10TA-Luft '86

mg/m³ (5% O₂)
1000

Diesel concept
Homogeneous lean burn concept
λ = 1-Konzept

6.36 4.6

2.0

0.2 0.3

0.15 0.1

mg/kWh

Fig. 20

mg/m³ (5% O₂)
"Diesel-Concept" - Engine on the test-bench

Fig. 21

"Diesel-Concept" - Engine on the test-bench

Fig. 22
NOx-reduction of diesel engines by combustion air conditioning
Ph. Boot, R.H.M. Borsboom

The excellent fuel economy of modern turbocharged diesel engines is coupled with NOx-emission. The high local temperatures which are inherent to the combustion principle are the origin of it. NOx is one of the gasses responsible for the air pollution and in a number of countries environmental regulations for land-based diesel engines are already in force for new engines to limit the NOx-emission. Areas with already a high environmental load, or a high contribution to the pollution from passing ships are preparing or have regional rules for ships as well. For marine applications IMO is preparing general legislation which is less severe than the regulations in Western Europe.

NOx-formation in the diesel engine is not only influenced by engine parameters, but also by ambient conditions. The effects of changing ambient conditions were investigated by experiments. Measured typical influences on NOx-emission are:
- decrease 0.4% per °C ambient air temperature increase;
- increase 0.5% per °C receiver air temperature increase;
- decrease 2% per gram water per kg dry air humidity increase.

In actual conditions influenced by the weather, the time of the day, the season and the place on earth, the actual NOx-emission can be lower, but also much higher than the emission at a reference condition like for instance the ISO-condition. By consequence ships produce more NOx in Western Europe and especially in winter than in the tropics when sailing at the same engine power. The NOx-emission is influenced most by the absolute humidity of the combustion air.

With the Combustion Air Conditioning (CAC) system, developed within the authors' company, the NOx-emission can be reduced to a level below the emission at ISO-reference conditions. The CAC-system consists of suction air temperature control and control of the humidity of the combustion air by means of water injection on the engine between the compressor outlet and the aircooler. The local air temperature after the compressor makes the water evaporate without external heat supply.

In engine tests water injector configurations, water pressures and different injection places have been tested. Increase of humidity by up to 14 g to 20 g water in total per kg dry air has been tested. This is equivalent to a weight of 50% of the fuel consumption. The total humidity in g/kg dry air is limited by the saturation condition determined by receiver air temperature and pressure. It may result in water drain from the air receiver.

No change in fuel consumption has been measured when applying humidification.

With the CAC-system on a standard engine the maximum NOx-emission can be reduced by 15–20% in moderate climates and far more in cold climates. When engine modifications and adjustments to reduce the NOx-emission cannot be applied further, because of increasing fuel consumption and soot emission, the CAC-system can give another 10 to 15% reduction without these problems. The total maximum actual NOx-emission will be reduced in this case by 35–50% related to the standard engine without CAC.

At decreasing load and temperature the water injection must be switched off, because the evaporation conditions of the water deteriorate.

In the first commercial application the system is fitted to a 4-stroke low NOx TM620 engine of 6100 kW at 400 rpm. The CAC-system can be applied on 2- and 4-stroke diesel engines and gas engines provided that they are turbocharged. Demineralized water is specified to prevent any deposit; but probably softened water will do as well. The system can be applied both on land-based engines and in ships. On board ships the evaporator that is heated by the engine cooling water is expected to produce water of sufficient quality for this purpose.

The system is simple and non-voluminous. On existing engines it can be placed as a retrofit. A high temperature air cooler upstream of the low temperature air cooler is advisable. In the Combustion Air Conditioning-system only very environment-friendly water is consumed.
INFLUENCE OF NOx-FORMATION BY COMBUSTION CONDITIONS:

- \( T_c \) - compression temperature
- \( \lambda \) - air excess factor
- \( c_p \) - specific heat of combustion air

EFFECT OF AMBIENT CONDITIONS ON NOx-EMISSION

- Ambient air temperature: \( -0.4 \) % per °C
- Receiver air temperature: \( +0.5 \) % per °C
- Absolute air humidity: \( -2.0 \) % per g H<sub>2</sub>O per kg dry air
- Barometric pressure: \( +0.05 \) % per mbar

**FIG. 1. EFFECT OF AMBIENT CONDITIONS ON NOx-EMISSION**

**FIG. 2. ACTUAL EMISSION**

LEGISLATION ON NOx-EMISSION

- In actual ambient conditions big variations in NOx-emission.
- Absolute limits in NOx-emission difficult to fulfill in all circumstances.
COMBUSTION AIR CONDITIONING
Humidification of combustion air is most effective in NOx-reduction.

LIMITS OF HUMIDIFICATION
- Condensation in air receiver influenced by:
  - receiver air pressure
  - receiver air temperature
- Condensation in air cooler influenced by:
  - cooling water temperature

PARAMETERS OF WATER INJECTION AFTER COMPRESSOR
- Droplet size, temperature and residence time
- Water quality
- Water distribution

TEST RESULTS WATER INJECTION
<table>
<thead>
<tr>
<th>Engine load</th>
<th>NOx-reduction (%)</th>
<th>NOx-reduction (% per g H2O per kg dry air)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1,9</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>2,4</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>2,5</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>2,5</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>2,5</td>
<td></td>
</tr>
</tbody>
</table>
COMBUSTION AIR CONDITIONING SYSTEM CONSISTS OF:
- Control of air humidity
  by water injection
- Control of suction air temperature
  by heating
- Control of receiver air temperature
  by cooling water temperature

**Effect of local conditions**
- Singapore
- Malaga
- Genoa
- Marseille
- London
- Rotterdam
- Hamburg
- Oslo
- Helsinki

Air heated to 30°C before
the compressor at local
humidity

**Effect of air heating**

**Effect of Combustion Air
Conditioning (CAC)**

- Air heated to 30°C, humidity
  10-15g water/kg dry air

**FIG 5. ACTUAL EMISSION**

MAXIMUM ACTUAL NOX-EMISSION
- at local conditions:
  10 - 20% higher than ISO
- with air heating:
  0 - 7% higher than ISO
- with Combustion Air Conditioning:
  8% lower than ISO

COMBUSTION AIR CONDITIONING
- Application conditions
  * Turbocharged engines,
    2- and 4-stroke,
    diesel and gas engines
  * 2-stage air cooler preferred
  * Engine load higher than 65-80%
    sufficient high temperature after compressor

- Application possibilities
  * Moderate and cold climate
    normally low air humidity
    West/North-Europe
  * Ships with on board water production
  * Stationary engines

WATER CONSUMPTION
- NOx/water ratio
  * 25-25 kg NOx reduction/1000 l water
- Water/fuel ratio
  * 30-37 kg water/1000 kg fuel
- Water/power ratio
  * 6 - 7.5 kg water/1000 kWh

1) per 1 g H₂O/kg air humidity increase.
5. Construction and Materials, Full Scale Collision Tests

5.1 The Probabilistic Approach

5.2 Detail Design

5.3 Full scale collision tests in combination with F.E.-calculations
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The probabilistic approach to ship structural design and maintenance - a review

N. Pegg

Abstract

This paper is a review of on-going research efforts in the international community to bring the application of probabilistic methods to fruition for ship structures. To date, probabilistic methods have not been accepted for the design and maintenance of ships to the same extent as they have for other types of structures. The very complex structural configurations and loadings of the ship structural engineering problem make the application of probabilistic methods both attractive and challenging, with much research work yet to be undertaken.

Introduction

Probabilistic or reliability methods have become a popular tool in the field of structural analysis. Unlike deterministic methods, probabilistic methods offer the opportunity to include directly the uncertainties associated with the statistical distributions of load and strength parameters. The engineer is given better insight and control over the factors which influence structural safety and can ultimately produce more rational efficient designs. The degree of acceptance of reliability methods has depended on the complexity of the structure and loading, the number of similar designs in existence, and the relative importance of safety for the structure. Ship structures do not benefit from well defined load or strength values, usually do not have many units of the same design, and in general, loss of safety from structural failure is not the overriding concern. As such, reliability methods have not had as significant an influence on ship structure design as they have had for other types of structures.

Despite the inherent difficulties associated with application to ship structures, reliability methods offer significant benefits in addressing the randomness and uncertainties associated with ship design. Many organizations throughout the world are addressing research efforts to this end. The author has had the fortunate opportunity to participate in three international working groups concerned with the application of probabilistic methods to ship structures. The U.S. based Ship Structures Committee (SSC), the International Ship Structures Committee (ISSC), and the Netherlands Ship Model Basin Cooperative Research on Ships (NSMB-CRS) whose work is only available to CRS members.
This paper does not present original work, but is a review of the current state of reliability methods for ship structural design and maintenance. It discusses probabilistic methods from the loads and strength aspects of ship structures and summarizes the most profitable areas of research in improving the application of reliability methods to ship structures.

**Current Practice vs Probabilistic Methods**

Current ship structural design and maintenance practice has evolved from years of experience in determining design loads, load effects, resistance models and safety factors. The method is one of working stress design where a characteristic value of design bending moment is derived from static balance on a design wave. The bending moment is transferred to a primary load effect (stress) by treating the ship cross-section as a uniform prismatic beam. This applied stress value is compared to a characteristic resistance stress value (such as yield), and a safety factor in the range of 1.6 to 1.8 [ISSC 1985] is used to separate the two. More advanced analysis methods such as finite element methods have been applied to ship structures but the underlying principles and faults of working stress design remain in place. A quote from Committee V.1 on Design Philosophy [ISSC 1985] describes the general state of working stress ship structural design:

*Even today, the techniques for predicting all the loadings to which an oceanic structure is heir and its consequent structural response are not altogether reliable, and the quantitative analysis of risk of failure is still beyond reach. Yet such inadequacies have never deterred the naval architect, for, although he really has no rational basis for predicting failure, he continues to design with bold unconcern of such a drawback by selecting a hydrodynamic loading in a manner which, although claimed to be empiric, is essentially arbitrary, and by imposing criteria of allowable stress intensities which, although intended to ensure that the material of hull construction will never be strained beyond its elastic limit, are at best nominal, and he does this by candidly ignoring that ship hulls are of cellular construction and that the material of all oceanic structures, which is beset by an accumulation of locked-in stresses and strains, is always working in the plastic region beyond the yield point. If it were not for the precious quality of ductility by which he selects the hull material (a quality which he never uses in his structural analysis), he would be a lost soul.*

Working stress design has the advantage of being relatively simple to use and easily incorporated into design codes. The fact that it has also provided good results for typical ship design increases resistance to move to a different design format. Chang [1990] argues that working stress or
'traditional' design of ships does have a probabilistic content in that characteristic values of load and strength and safety factors have been chosen to give an acceptably low probability of failure. He also points out that design codes based on probabilistic methods do not have to be more complicated than the traditional approach and that load and resistance factor design (LRFD) codes, which do not stray too far from the working stress approach but are calibrated by higher order probabilistic methods, have been successfully adopted by other agencies.

The main disadvantage of deterministic working stress design is that all uncertainties associated with defining the load effect and structural resistance are tied up in a single safety factor. The designer is not given any leeway to apply more accurate knowledge of the design process. The deterministic safety factor also does not reveal how or to what level safety is achieved in the design, as there is no consideration given to the likelihood that the ship will see its design condition. Reliability methods allow specific uncertainties to be defined for each step of the design and analysis process; therefore, they give the designer a more rational understanding of how safety is derived and may also provide a means to control some of the uncertainties to provide a more efficient and safer ship.

Design and Maintenance

The incorporation of inspection and maintenance in the design process has received considerable attention for producing more efficient, safer designs. A considerable amount of work has also been done in developing planned maintenance practices based on probabilistic assessment of the occurrence and growth of fatigue damage. Predicting when and where fatigue damage is likely to occur allows planned inspection and maintenance to be undertaken to maintain a minimum level of safety throughout the life of the structure. Being able to include this process as part of a design philosophy can produce more efficient 'fail-safe' structures in which damage expected to occur during life can be managed to achieve a known level of safety. Designing ships which are 'inspectable' is the first step in this process. The Ship Structures Committee is one of several US agencies involved in studying this process [Bea et al 1991].

Reliability Methods

Several texts such as Thoft-Christensen and Baker [1982] cover the basics of reliability methods extensively, and several computer codes are easily available to calculate safety indices. Because of the difficulties in defining the ship structure problem and its parameters, it became evident in the 1980s that reliability methods would not deliver true probabilities of failure and the term 'notional probabilities
of failure' was coined, indicating that reliability analysis was more of a comparative design process than an absolute one.

Most literature on structural reliability methods refers to three levels of reliability analysis, depending on the level of statistical information known about the parameters in the problem. These are well described in several texts and papers. Level 1 uses only one characteristic value of the problem parameters. This is the basis of working stress and load resistance factor (LRFD) design where a safety factor or load and resistance multipliers are used to separate a characteristic strength value from a characteristic load value. Level II methods use two characteristic values, the mean and coefficient of variation (COV), and also assume some type of distribution of the parameters (e.g. normal, lognormal). There are various developments of Level II methods such as FORM (first order) and SORM (second order). These are the most commonly used methods for structural analysis and are available in commercial software. Level III methods require full joint probability descriptions of all of the parameters. This information rarely exists; hence, these methods have not generally been used in structural applications.

Level II reliability codes need two basic inputs which may be very difficult to obtain: limit state descriptions for all of the possible failure modes, whether structural failure is defined as collapse or unfunctionality; and, statistical characteristics in the form of means, COV matrices and distribution types of all of the parameters in the limit state.

The main output of level II methods is a safety index $\beta$, for the particular limit state of concern. A secondary product of reliability analysis, but one of probably equal importance, is the sensitivity of the safety index to the input parameters. While the safety index tells the analyst what the probability of failure is, the sensitivity factors tell him what parameters most influence the safety and where the most efficient design tradeoffs can be made.

To date, reliability methods have addressed probabilities of failure associated with physical parameters and have not included human error. Human error is by far the most significant cause of ship loss even when the loss is a result of structural failure. Several researchers are trying to quantify and include human error in the reliability assessment process; this is a very difficult task which lies mainly outside the traditional fields of engineering study. True safety probability estimates of a structure must eventually include this aspect of failure analysis.
Loads and Load Effects

The random nature of the ocean environment has made ship and offshore structures natural targets for the application of probabilistic methods. The statistical description of sea state has probably received more attention than any other marine related topic in the past few decades. Still, according to ISSC [1991], the uncertainties associated with load prediction are an order of magnitude greater than those of strength assessment.

The limit states being considered in reliability analysis define the load or loads that need to be included in the analysis. The two basic categories of loading are the extreme and lifetime cumulative values for ultimate and fatigue failure limit states, respectively. The load development process begins with describing the ocean environment through a representative spectrum and associated wave property probabilities. Figure 1 shows six wave height probability distributions used in a parametric study of fatigue life for Canadian navy vessels in northern Atlantic operation: Ochi North Atlantic [Sikora et al 1983]; North Atlantic Annual and Winter [Bales et al 1981]; Norwegian Annual and Winter [Bales et al 1981]; and, one specifically derived from a history of Canadian warship operations (MARCOM).

Uncertainties arise in defining the load environment through (Nikolaidis and Kaplan [1991]): definition of wave spectra; the effects of short crestedness; sea directionality; use of visually assessed wave heights; and, the action of the captain against heavy weather.

The wave environment is translated to load effects through transfer functions (response amplitude operators – RAOS).
which are functions of ship speed and heading. These may be
derived through linear 2D strip theory, higher order
nonlinear strip theory, 3D panel methods or through empirical
methods. Upon defining probabilities of ship speed and
heading and life at sea, a lifetime load effect distribution
can be derived as in [Sikora et al 1983] who use generic
empirically derived RAOs. This method was applied to the wave
height probabilities of Figure 1 to derive midships vertical
bending moment exceedance curves for fatigue life estimation
as shown in Figure 2. Although these curves appear
reasonably close together, those familiar with fatigue
analysis will realize that the differences in these curves
have a very significant effect on fatigue life prediction (in
the order of 100 percent between the top and bottom curves).

Uncertainties which exist in translating the load environment
to load effects are: evaluation of still water bending
moment; development of transfer functions - RAOs;
nonlinearities in transfer functions - hog/sag ratio;
definition of ship operational profile; load combination
models - wave and slamming; and, models to predict slamming
loads. Dalzell [1991] presents an excellent review of the
load requirements for probabilistic analysis. He argues that
a combination of linear frequency domain, quasi-linear time
domain and fully nonlinear time domain analyses is required
to develop proper load history data from all relevant load
components.

One of the most significant advances to be made in the
application of reliability methods to ship structures is in
quantifying the load related uncertainties. There has been
surprisingly little effort in this area in comparison to
other topics in reliability theory. Nikolaidis and Kaplan
[1991] summarize some of this work, most of which comes from
erlier efforts by Guedes Soares and Moan [1985]. They divide
uncertainty into two categories, natural and model. Natural
uncertainties are those arising from statistical natural
scatter in the data and can be reduced with increased sample
size. Model uncertainties arise from inaccuracy in describing
a process and result in both scatter and a systematic bias.
Modelling uncertainty is not a random quantity and is not
reduced with increased sample size, but only through improved
understanding and description of the physical process.
Extreme load uncertainties have a significant natural
uncertainty content while fatigue load uncertainty is a
function primarily of model uncertainty. Model uncertainty
factors can be estimated by comparison to experimental data
or to more refined models.

Load uncertainties have been described in Nikolaidis and
Kaplan [1991] in terms of a bias factor B, which multiplies
the predicted quantity \( X_p \) to estimate the true quantity \( X \),
and a coefficient of variation, \( \text{COV} \). Simplified versions of
the bias factors based on wave height, $H_s$ are given and repeated here as follows:

- Spectral shape: $B = 1.0$ for $H_s > 5$m or ship length $L < 250$m and $B = 2.0 - 0.2 H_s$ for $H_s < 5$m or $L > 250$m and COV = 0.1
- Shortcrestedness: $B = 1.0 - 0.0077 H_s$ and COV = 0.05
- Directionality: $B = 0.981 + 0.018 H_s$ and COV = 0.1
- Visual Wave Height: $B = (0.75 H_s)/(H_s - 2.33)$ and COV = 0.17
- Captain's Response to Heavy Weather: $B = 1.0$ to 1.25

Still water bending moments may be relatively easy to derive from a known condition of a vessel but coefficients of variation can be very large depending on the type of vessel. COVs are reported [Nikolaidis and Kaplan 1991] to range from 0.29 for container ships to 0.99 for tankers in a ballast condition. Committee V.1 of [ISSC 1991] uses a Rayleigh distribution for still water bending moment in their reliability assessment of an offshore production vessel. The COV used for still water model uncertainty is 0.10 for panel failure and 0.05 for hull girder ultimate strength. These values are lower than those reported by Nikolaidis and Kaplan [1991], which supports one of their underlying themes that model uncertainties used to date, even in design codes, are much too low. The approach used in the NSMB-CRS project [Gran and Loseth 1991] is to derive a spectral representation of still water moments based on the loading book using draft and trim as random variables. This model will serve as a subroutine input to the DnV reliability code, PROBAN.

Bias for vertical bending moment RAOs are reported in [Nikolaidis and Kaplan 1991] as $B = 1.22 - 0.005 H_s$ for all factors except hog/sag ratio which is given as a function of the block coefficient as $B_\text{s} = 1.74 - 0.93 C_B$ and $B_\text{H} = 0.26 + 0.93 C_B$ for sag and hog respectively. A COV of 0.35 is reported for general bias of RAOs and 0.12 for the effects of hog/sag ratio. Committee V.1 [ISSC 1991] used a nonlinear strip theory and time series approach to derive bias for linear strip theory results of $B_\text{s} = 1.15$ and $B_\text{H} = 0.85$ for sag and hog respectively, with a COV of 0.03. For sagging vertical bending moments, RAOs from linear strip theory are almost always unconservative.

The problem of load combination is one which has not been resolved satisfactorily. When combining loads from different time bases, it is particularly difficult to establish what and where the maximum combined value is. Still water, wave and slamming induced bending moments all occur within different time frames. Within the regular wave induced loads, vertical, horizontal and torsional components have to be combined; the effects of lateral pressure may also be important for the limit state of concern. Correlation coefficients for all of the loads of concern to the limit state being investigated are required, but are rarely
available. Monte Carlo simulation (MCS) can be used to generate statistical parameters for verification of combination models but is computationally intensive and currently computationally impossible for developing lifetime load profiles where statistically significant data would have to be generated for all of the ship operational permutations (>2000 [Dalzell 1991]). Nikolaidis and Kaplan [1991] compared Turkstra's Rule, the summation of component peaks, and the square-root-of-the-sum-of-the-squares (SRSS) against MCS predictions for combined slamming and wave loads. They found that Turkstra underestimated the combined load with a bias of 1.17, the peak summation overestimated the load with a bias of 0.72 and the SRSS alternately over and underestimated the load with a bias of 1.01 with a slightly higher COV of 0.12, compared to 0.11 for the other two methods. The study of Committee V.1 [ISSC 1991] used a combination parameter to multiply the still water loads in summation with the wave load with values ranging from 0.61 to 0.41 depending on the time span of the load input.

The NSMB-CRS project is primarily concerned with load combination models for probabilistic analysis and is combining theoretical development with full scale measurement data to predict the statistical parameters for combined still water, wave component, slamming and pressure loads. For some types of loads such as slamming and pressure, existing models to predict the load effects from the ocean environment and ship operational profile are inadequate.

Strength

The second part of the reliability equation is the statistical description of the structure's ability to resist the load effects. Three components make up this description: the geometry, the material, and the model describing the resistive capacity. Uncertainties for geometry and material data have been given in many published reliability studies [ISSC 1985, 1988, 1991, Mansour et al 1991] and will not be repeated here. These should be verified for the problem at hand but in general have COVs less than 0.05 for geometric parameters and less than 0.10 for material parameters. Biases are almost always greater than 1.0 indicating nominal values are conservative.

Reliability analysis of ship structures, which consist of complex welded stiffened shells should be undertaken by system reliability methods which allow assessment of the safety of the entire structure, not just component parts. To date, no sufficient methods of applying system reliability methods to ship type structure have been developed [Nikolaidis and Kapania 1990]. Computational requirements, simplifying assumptions which are not applicable to ship structure, and difficulties in measuring structural redundancy are cited as the main deficiencies. System
reliability is closely linked to structural optimization procedures, and it can be envisioned that eventually optimum ship structural designs can be developed using system reliability requirements as optimization constraints.

The most attractive method of analyzing the response of complex stiffened shells of which ships are constructed, is finite element analysis (FEA). Incorporating the statistical probabilities of the problem is not as straightforward when using FEA as it is for closed form limit states formulations. One approach to incorporating the randomness of the structural parameters in FEA is to use simulation techniques (for example, MCS) where the parameters are varied according to their distributions in a series of FEA runs to produce load effect statistics. This can be very CPU intensive, but methods for improving the efficiency of these simulations are appearing in the literature. Computational considerations become more severe when the limit state involves nonlinear behaviour, such as for ultimate strength assessment.

An area of current interest in the academic community, but of tremendous potential benefit in future application, is incorporating reliability methods directly into FEA codes [Moore 1988, Spanos and Brebbia 1991]. This eliminates the need to establish approximate limit state equations to describe failure, as FEA directly predicts (to the accuracy of the model) structural behaviour such as displacements, stresses, onset of plasticity, loss of stability, vibration, etc. The randomness of the structural parameters is used in the FEA calculation so that output load effects include the structural uncertainties.

Just as uncertainties for closed form equations of limit states need to be established, so must they be determined for FEA. This is in some respects much more difficult, as the uncertainty will depend partially on the actual modelling approach used, which may require a subjective evaluation. Typical FEA meshes usually overestimate the stiffness of the structure, particularly if relatively coarse models are being used to model global ship response. For the particular problem of determining twist angle for torsional response in an open hatch containership, Nikolaidis and Kaplan [1991] report a bias of 1.4 with a COV of 0.18 against model test results. They concluded that it is difficult to predict the warping torsion component with FEA. For the case of longitudinal deck stresses in pure bending, FEA overpredicted the results to give a bias of 0.93 and COV of 0.17 compared to beam theory which gives values of 0.94 and 0.10, respectively. Committee V.1 of [ISSC 1991] used FEA for ultimate strength calculations and used a bias value of 1.22.

No comprehensive studies on establishing uncertainties arising from FEA were found in the literature. Committee
II.1 of [ISSC 1991] undertook a comparative FEA study of deflection and stress in a midship webframe bulkhead of a large tanker [Zillioto et al 1991]. The extent and grid of the model, boundary conditions and load representation were all left up to each of the ten participants in the study, with only the problem geometry via ship drawings and the basic load condition being defined. Results for displacements vary considerably, primarily from 2D and 3D representations of the problem boundaries. In analyzing these results the smallest COV for displacement was for prediction of the bottom centerline deflection with a value of 0.4. Stress results compare much better with a COV of 0.11 for stress in a bracket flange. For this case, as for other studies on FEA uncertainty, the sample size is really too small to draw any hard conclusions. Committee II.1 of ISSC is continuing with its comparative FEA studies to further information on uncertainties. The current attempt will be for a structure with experimental results so that a bias value can be obtained as well as COVs.

Limit States for Ship Structures

Some of the limit states to be considered for ship structures are: fatigue, defined by a certain length of crack growth; fracture; local yielding of plates and stringers; excessive displacements (permanent set) of plating or grillages; excessive vibration; buckling of plates and stringers or grillages; and ultimate strength of the hull girder.

Various limit state equations have been proposed for these failure modes. These are usually of closed form but numerical solutions have also been used [Ferro and Cervetto 1984]. Committee V.1 of [ISSC 1991] gives limit state equations and bias factors for local plate failure and ultimate hull girder collapse. The work presented by this committee is a very insightful consideration of practical application of reliability theory.

Fatigue limit states have been given fairly extensive treatment in the literature, especially for offshore structures where the 'hot spot' fatigue crack initiation points are reasonably well defined and have been modelled extensively. A good discussion of crack initiation fatigue failure mechanisms using the Palmgren Miner formulation and SN curves, formulated in a reliability format, is given by Wirsching and Chen [1987]. The limit state is written as the resistance to cumulative fatigue damage defined by the dimensionless sum, $\Delta$, usually equal to 1.0 but a random variable, and the cumulative damage from some representation of the lifetime applied stress.

$$g(x) = \Delta \cdot \frac{T B^m}{K}$$

$T$ is the time of exposure at the mean stress value, $B$ is the
bias on the fatigue model, m and K are material fatigue parameters, and Ω is defined by different methods for stress damage such as the deterministic, spectral and Weibull models given by Wirsching and Chen. B is derived from several uncertainty sources such as geometry, seastate description, wave load prediction, dynamic effects of structural analysis, and stress concentration factors [Nikolaidis and Kaplan 1991]. Bias values given by Wirshing and Chen range from 0.7 to 0.9 with COVs ranging from 0.14 to 0.5 from various sources. They also list COVs for material SN data which range from 0.43 to 1.36. COVs are summarized for all sources of bias by Nikolaidis and Kaplan [1991] with total COV values of 2.21 for ships and 3.42 for offshore structures with contributions from stress concentration and load description being the most significant, respectively. Although noted, no reason is given for offshore structures having a higher uncertainty than ships. In comparison with other limit states the uncertainties associated with fatigue prediction are very high. This is primarily due to the fact that fatigue models are very sensitive to the stress history input and material parameter definition. Load definition for fatigue requires input from all loads and hence the difficulties discussed in the previous section on load definition and load combination of still-water, wave, and slamming induced components are very relevant. A significant contribution to this uncertainty may be due to the fact that both the applied stress and material resistance parameters neglect the presence of residual stress. Efforts to include residual stress in the applied stress calculations and in the SN curves may result in considerable reduction in uncertainty.

Fail-safe design philosophy accepts the existence and growth of cracks and relies on being able to detect and repair cracks before they affect the structural integrity of the system. Cracks are considered to cause failure once they reach a critical length after which further propagation occurs quickly. As in the crack initiation SN model, a limit state giving a pass or fail criteria for the state of crack length in the structure is required. Madsen et al. [1987] describe a reliability model based on the Paris Crack Growth Law as:

\[
g(x) = \int_{a_0}^{a_c} \frac{1}{Y(a)^m(Y(a)da)^m} da - CNS^m
\]

where a is the crack length, C and m are the material parameters for crack growth, a_0 is the initial crack length on build, a_c is the critical crack length, N is the number of cycles in addition to those that cause a_0, S is the stress range in the far field and Y(a) is the geometric factor at the crack location.
The reliability of a structure can be continually maintained through periodic inspection and repair of all detected cracks above a certain limit. Madsen et al. [1987] present two formulae which can be applied in considering crack repair effects. For a chosen size of crack to be repaired $a_{\text{rep}}$, the number of cycles which are predicted to occur to cause this size of crack is $N_{\text{rep}}$. The value of $N_{\text{rep}}$ can be used to estimate inspection intervals and can be determined by replacing $N$ and $a_c$ in the crack growth limit state equation by $N_{\text{rep}}$ and $a_{\text{rep}}$, respectively.

After inspection and repair, the maximum crack size present in the vessel becomes $a_n$ and the material parameters $C$ and $m$ may also change due to the repair practice to become $C_n$ and $m_n$. The crack growth limit state then becomes one of a critical crack size occurring after the repair and can be rewritten with the new initial crack size and material parameters. Using this method, a minimum reliability index, based on the crack size $a_{\text{rep}}$, can be maintained in the ship if repair is made whenever a crack of size $a_{\text{rep}}$ is detected. Figure 3 shows this process schematically.

![Figure 3: Reliability vs Time Including Updating for Inspection and Maintenance](image)

There are many uncertainties in crack growth prediction models which still need further research. Distributions of $a_0$, $a_c$, $a_{\text{rep}}$, and $a_n$ need to be established. Also distributions of $C$, $m$, $C_n$ and $m_n$ need to be determined for the details of interest. The geometry factor can be calculated from FEA or formula but also needs probabilistic description. Bias factors for using the Paris Crack Growth Law also need to be established. Inspection uncertainty, incorporated into the COV of $a$, is probably the largest unknown in applying this method to ship structures. The probability of detecting cracks in a complex ship structure, often under very
difficult inspection conditions, is likely still too low to accept this method fully for ship inspection and maintenance planning.

Conclusions and Recommendations

Activity in applying probabilistic methods to ship structure design and maintenance is considerable and should be encouraging to proponents of these methods. The difficulties associated with establishing uncertainties in the load, strength and limit state models are still considerable, and it is difficult to imagine that a wholly reliability-based design code will be adopted for ship structures in the near future. However it is likely that components of reliability methods will be incorporated into design practice and allowed by design authorities as an alternative to traditional methods. The many areas in need of further development should keep researchers busy for some time. Some of these are:

- more accurate RAO models with associated bias and COVs to incorporate nonlinear and 3D effects;
- determine bias for specific wave spectral models;
- develop models for slamming and hydrodynamic pressure load;
- develop probabilistic load models for load components other than vertical bending moment;
- formulate and verify load combination procedures;
- develop reliability based FEA for large models develop bias and COVs for FEA
- develop system reliability methods for continuous stiffened shell structure;
- incorporate human error into the safety assessment process;
- develop improved methods for crack detection on ships to quantify probability of detection; and,
- determine target reliability values for design, maintenance and damage assessment.

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ABSTRACT
During the recent years there has been a significant development in tools for probabilistic computations and the experience in use of these methods is growing. The probabilistic methods enable to quantify the effect of uncertainties in design of structures in a rational manner. Such methods may in practice be used for novel designs, but in most cases such analyses require an effort and a data background that is in excess of practical limitations.

On the other hand the rules for design of ship hulls are quite simple, efficient to use and gives easily controllable results. The rules shall reflect the state of the art methods that may be implemented through computer software and the gathered data on structural performance. The rules also reflect the accepted level of safety in design of traditional ship hulls.

Through a calibration scheme the results from probabilistic methods is used to narrow the gap between the two approaches. A reliability based formulation of the buckling capacity in deck panels have been applied to study the performance of the DnV rules against more advanced formulations.

INTRODUCTION
The ship designs are becoming more optimized often making local criteria such as panel buckling more critical than the overall strength, represented by the sectional modulus. This motivates to focus on the local criteria in the rules, such as the buckling criteria of stiffened panels studied herein.

The main reason for using probabilistic methods in rule calibration is to develop practicable design rules which are based on state-of-the-art physical and statistical knowledge. Other considerations behind a probabilistic calibration of design rules are:

- Simple design rules are easier to use and more controllable than advanced reliability analyses. Probabilistic calibrated design rules will, however, contain an extract of the more advanced analyses.
- The uncertainty in each individual variable is assessed as part of the input preparation to the reliability computations.
- The choice of safety factors is documented and may be updated based on new methods and improved data.
- The discrepancy between simple methods and advanced computations is reduced.

A probabilistic calibration is usually a costly process since an extensive data gathering, a complex reliability model and a large computational effort are needed. The calibration provides, however, a systematic rule development where each part of the calibration process can be documented and checked against physical observations.

Calibration of design rules may be performed with different goals in mind. The purpose of one calibration study may be to fit some strength formula to a number of test results in order to achieve a defined target reliability level for a range of designs. If the format of the limit state in the reliability computation is the same as that of the design rule, the
partial safety factors can in this case be derived from the most probable failure point and by specifying characteristic values for the design rule variables.

If the purpose of the calibration study is, however, to fit a simple design rule to an advanced reliability computation, the above procedure is not applicable. The reason is that the mathematical formulations in the advanced reliability analysis and the rule formula are different and the connection between stochastic variables in the limit state and characteristic values in the rules need not be unique. In this case the calibration procedure must reflect the difference in the formulations and the input data.

This is the case when deck panel reliability computations, based on FEM analyses or other numerical solutions for calculating the buckling stresses is to be used in the calibration of analytical design rules. Different methods are hence applied in the reliability and the rule formulation and the most probable failure point does not necessarily correspond to any design rule value.

The link between the reliability formulation and the design rule is, however, present since the same panel is considered in both formulations. By assuming that the dimensions of the panel will be chosen on the limit of the design rule (by a clever design), the calibration procedure can cover for a set of such designs. The optimization procedure is outlined in Figure 4.

THE RELIABILITY FORMULATION

The Limit state

The buckling of deck elements are considered as the critical failure mode. This corresponds to a critical sagging condition that may lead to total collapse and loss of ship.

The limit state for hull girder collapse is generally written as

\[ g < 0 \quad \text{; failure domain} \]
\[ g = 0 \quad \text{; failure surface} \]
\[ g > 0 \quad \text{; safe domain} \]

where

\[ g = \sigma_u - \frac{M_s + M_w}{W_p} \]

\( M_s \) is the still water moment.
\( M_w \) is the dynamic wave moment.
\( \sigma_u \) is the collapse strength of the stiffened deck panel.
\( W_p \) is the section modulus of the hull girder section in position of the deck panel.

Each of these entries in the limit state are described further in the following. The model is implemented as a limit state for use with the computer program PROBAN, Olesen and Tvedt (1989).

Loads

A Tanker hull is usually a full form design with little nonlinear effects. Results from a linear strip theory is considered appropriate in this analysis. In this example some simplifications are made in the analysis:

- Only zero speed head seas are considered.
- The North Atlantic environment is assumed over the full time period.
- The specified design still water condition for the vessel is combined with the computed wave bending moment.
A scaling related to world wide operation is included.

The above assumptions affects the loading only. This may here be reflected through the choice of the target reliability as determined from an ensembl of currently acceptable designs.

The specification of sea states, or wave conditions, is given in terms of significant wave height $H_s$ and peak period $T_p$. Based on data, a scatter diagram, a joint probability distribution $F(H_s, T_p)$ is determined as

$$F(H_s, T_p) = F(H_s)F(T_p | H_s)$$

where $F(H_s, T_p)$ is the joint probability distribution, $F(H_s)$ is the marginal distribution of significant wave height and $F(T_p | H_s)$ is the conditional distribution of peak period given significant wave height.

The marginal probability distribution for significant wave height is represented by a three parameter Weibull distribution,

The sea state parameter for the worst 3-hour storm is determined as the largest significant wave height with the corresponding period. By independence, the largest significant wave height, $H_{s, max}$, has the cumulative probability function

$$F_{H_{s, max}}(H_s) = F(H_s)^N = \left(1 - e^{-\frac{H_s - 0.594}{2.290}}\right)^N$$

where $N = 2920$ is the number of sea states of 3 hours duration in one year. A transformation is performed describing $H_{s, max}$ by a standard normal variable $X_1$ as:

$$H_{s, max} = 0.594 + 2.29 \left(-\ln\left(1 - \exp\left(-\ln\phi(X_1)\right)\right)\right)^{0.722}$$

The conditional probability density function for $T_p$ by given $H_s$ is chosen as the log-normal distribution, with distribution described as:

$$F(T_p | H_s) = \phi\left(\frac{\ln T_p - \mu}{\sigma}\right)$$

The parameters $\mu$ and $\sigma^2$ are:

$$\mu = 1.187 + 0.833 H_s^{0.242}$$
$$\sigma^2 = 0.1177 e^{-0.312 H_s} + 0.00541 e^{-0.041 H_s}$$

The conditional distribution of the peak period $T_p$ for given $H_{s, max}$ is then given by a transformation of the conditioned variable $T_p$ into a standard normal variable as:

$$T_p = e^{\mu (H_{s, max}) + \sigma (H_{s, max}) X_2}$$

The above extreme value consideration on significant wave height $H_s$ is only valid for problems dominated by wave induced forces.

To describe the response characteristics of the ship a 5th order polynomial has been fitted to the standard deviation of response, $\sigma_s$, as

$$\sigma_s = H_s (183.5 - 111.2 T_Z + 25.2 T_Z^2 - 2.54 T_Z^3 + 0.119 T_Z^4 - 2.14 \times 10^{-3} T_Z^5)/10.58$$

The average zero crossing period, $T_r$, for the response as function of peak period, $T_Z$, in the wave spectrum was found to be, see also Figure 2.:

$$T_r = 2.269 - 1.179 T_p - 0.0417 T_p^2 + 0.0005 T_p^3$$

The significant single amplitude stress is determined as $2 \sigma_s$, and the zero up-crossing period is determined from its relation to the peak period for the Pierson Moskowitz spectrum as $T_p = 1.41 T_Z$. 

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Figure 1. Basis axial stress in panel due to wave bending as function of $T_z$.

Figure 2. The period of response cycles, $T_r$, as function of $T_p$. 
The extreme wave bending moment, $M_w$, or $X_4$ is determined within the extreme sea-state with a one year period. The vertical bending moment in the hull girder may then be considered as a stationary Gaussian process. The distribution of the largest bending moment $M_w$ can be obtained by assuming that crossings occur independently, i.e., they constitute a Poisson process, so that

$$F_{M_w}(m) = e^{-\nu_m D}$$

where $\nu_m(x)$ is the mean up-crossing rate of the level $m$ for the process $X(t)$, and $D$ is the duration of the sea-state. The maximum wave bending moment within the sea-state, $M_w$, is then expressed in terms of the standard normal variable $X_4$ by

$$M_w = \frac{1}{2\sigma_2^2 \ln\left(-\frac{T_r}{D} \ln\Phi(X_4)\right)^2}$$

The duration of a specific sea state, $D$, is taken as 3 hours.

The model uncertainty, $X_6$, includes a scaling from the North Atlantic climate to the worldwide operation by a factor 0.8, as derived Biltner-Gregersen et al. (1992). In CL30.6 (1991) a coefficient of variation of 10% on the standard deviation of response determined from strip theory analysis was derived by comparisons with measurements.

The uncertainty in non-linear correction, $X_7$, is for a full form vessel like this tanker (large $C_B$) are not as important as for slender ships. This value is here included only as an additional model uncertainty.

The still water bending moment, $M_{sw}$, is the static contribution to the vertical bending moment caused by buoyancy and the static load distribution of the ship. Since cargo and ballast are being changed over time the still water bending moment will also change over time.

Based on all relevant loading conditions the mean sagging condition is determined (deck in compression). In this analysis it is taken as the specified still water condition for this vessel which is slightly less than the rule value. From Soares (1984) the COV. of 30% was determined. In future analysis this COV. should be based on the possible variations of the still water moment for the considered vessel Gran (1991). The still water bending moment was included as an axial stress in the deck with a mean of 30 MPa and a C.O.V. of 0.3. It is assumed that a random still water load condition may be combined with the extreme wave bending moment.

Buckling Strength

A simplified model is adopted in which the ultimate buckling capacity $\sigma_u$ is given as a function of 13 physical parameters, i.e.

$$\sigma_u = \sigma_u(x_9, x_{10}, ..., x_{21})$$

The parameters are:

i) Geometry of plate and stiffener, depending on type of stiffener profile, $x_9, ..., x_{16}$.

ii) Geometrical imperfections, $x_{17}, x_{18}, x_{19}$.

1. Global stiffener imperfection; $x_{17}$ or $\delta_1$.
2. Sideways/torsional stiffener imperfection; $x_{18}$ or $\delta_2$.
3. Local plate imperfection; $x_{19}$ or $\delta_3$.

iii) Material description, $x_{20}$ and $x_{21}$

1. Yield Stress, $x_{20}$
2. Youngs Modulus, \( x_{21} \)

(strain hardening excluded, \( E_T = 0 \))

The basic assumptions behind the buckling model are described and discussed in Steen (1989) and Hauge et al. (1992). By increasing the deflections the capacity is determined as the maximum axial force/stress of the panel.

The buckling model has been verified by comparing its deterministic strength assessments against some recent numerical studies presented by Smith et al. (1991). It was found that the difference for the cases shown are generally of the order of 15% on the optimistic side. However, the present model shows extreme unstable behaviour for slenderness ratios \( \lambda \) above say 0.8. (\( \lambda \) is defined as the square root of the relation between elastic Euler buckling stress and yield stress). This is in qualitative agreement with the results given by Smith et al. (1991).

The general strength difference of the order of 15% compared to the referred article seems to be high. However, the buckling stresses are very sensitive to sideways imperfections of the stiffeners for the geometrical ranges considered, making the strength assessments uncertain. Smith et al. (1991) do not give values for these sideways imperfections as used in their study. As a conclusion, it seems that the present model captures the basic physical behaviour of stiffened plate buckling and that it will be well suited for reliability studies.

The statistical data used in the reliability studies for the geometrical imperfections are determined by Steen (1992), see also Table 1, where the variables \( X_{17-19} \) are given.

THE RULES

According to DnV (1991) several buckling limit states are to be evaluated for the case of critical sagging conditions. These correspond to several buckling modes and they may be summarized as:

\[
c_i \geq 0 \quad \text{acceptable DnV rule (i = 1, 2, 3, 4)}
\]

where

\[
c_1 = \sigma_c - \gamma_1 \frac{1}{W_D} (M_s + M_w);
\]

plate buckling

\[
c_2 = \sigma_c - \gamma_2 \frac{0.85}{W_D} (M_s + M_w);
\]

lateral stiffener buckling (Euler)

\[
c_3 = \sigma_c - \gamma_3 \frac{0.80}{W_D} (M_s + M_w);
\]

torsional stiffener buckling

\[
c_4 = \sigma_c - \gamma_4 \frac{0.80}{W_D} (M_s + M_w);
\]

web stiffener buckling

The factors 1.0, 0.85 and 0.8 are the allowable usage factors (partial safety factors) defined in the rules and the factors \( \gamma_i \) represent changes in usage factors determined from the calibration. The buckling strength in the respective mode, \( \sigma_c_i \), are taken according to DnV rules (1991). \( W_D \) is the section modulus of the hull girder in the position of the deck panels. \( M_s \) is the still water moment and \( M_w \) is the dynamic wave moment defined in the rules corresponding to a return period of 20 years.

The section modulus \( W_D \) is a pure geometrical constant and is treated as a fixed parameter in the present study. In the optimisation process of the code calibration study presented here, sectional parameters like plate thicknesses, stiffener heights of deck panels etc. are variable parameters that determine \( W_D \).

The DnV rules (1991) loads are summarized as follows:

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Still water bending moment, in sagging, for a 20 year return period:

\[ M_s = 0.065 C_w L_p^2 B (C_B + 0.7) \] [KNm]

Wave induced moment bending, in sagging:

\[ M_w = 0.11 C_w L_p^2 B (C_B + 0.7) \] [KNm]

where the following notation is used:

- \( L_p \) - ship length between perpendiculars
- \( B \) - ship breadth
- \( C_B \) - block coefficient
- and \( C_w \) is a wave parameter depending on ship length.

**PANEL DESIGNS**

The rule criteria on buckling effectively limit the range of allowable designs with respect to the local dimensions of the stiffened panels. In this study some of the most important parameters as given below will be varied within practical limits. There are parameters that may be chosen by the designers, and the rules has to be checked for a range of such possible designs. To create a set of designs the parameters are here determined by use of a Monte Carlo simulation.

![Figure 3. Definition of geometry variables.](image-url)

Here the designer chosen parameters and the specified ranges are:

- the plate thickness, \( t \), [14, 26] mm
- the the height of the stiffener (the web height), \( h_w \), [200, 500] mm
- the thickness of the stiffener (the web thickness), \( t_w \), [12, 30] mm
- the width of the flange of the stiffener, for Tee-profile, \( b_f \), [100, 300] mm
the thickness of the flange, for Tee-profile, $t_f$, $[12,30]$ mm

Normally the designer may also chose the transverse frame and stiffener spacing, but these dimensions are kept constant here. The yield stress is also kept constant at a high tensile steel grade, NV36. From the above range of parameters, designs that are on the limit of the rules are determined by iteration.

EXAMPLE OF CALIBRATION RESULTS

The optimization aims to determine possible improvements in terms of a reduced spread in the reliability indices computed from the more advanced probabilistic buckling model. Tee- and I-profiles have been studied. Other profiles and designs are currently being studied by DnV.

For the panels with Tee-profiles designed according to current ship buckling rules, the annual reliability index, $\beta$, is estimated to be in the range 3.53-4.72. The lowest values are valid for the minimum weight designs. This lead to a choice of a target reliability index $\beta=3.71$, to be used in the calibration. For the applied reliability formulation and input data, this target reliability index is considered equivalent to accepted current practice. The target reliability is also in accordance with CL30.6 (1991) for serious failure in a redundant structure. Only one plate field and stiffener is considered, and adjacent panels may have a larger capacity by e.g. less imperfections. However, the redundancy is normally not large.

The objective of the calibration is to reduce the weighted deviation from the target reliability. This is evaluated according to the penalty function, see Figure 5, giving the weight on each reliability indices related to the chosen designs. The parameters to be used in the optimisation were the scaling factors $\gamma$, or usage factors, on each failure mode.

When the scaling factors are equal to one this implies no change in the current rules. It turned out that it was not possible to reduce the spread in the reliability indices by changing these scaling factors for the Tee-profiles, for the considered ship and range of design parameters. Other changes in rule formulations and scaling parameters may improve the situation and this will be investigated further.

For the flat bar profiles it is possible to improve the situation, according to this procedure, and a rule change may follow for this type of profiles. After the calibration some I-profile designs with low reliability were rejected without any significant increase in the steel weights. The implicit requirement to the stiffener strength is slightly increased to give comparable reliability to that of the Tee-profiles. The increased requirement come into play if the designer would chose to utilize increased plate thicknesses, that may be due to other requirements, to reduce the stiffener dimensions. In Table 3, the results for the low weight designs are shown after the calibration. It may be seen from the wgt column describing the weight of the deck panel relative the basis design, that the steel weight of the panel in this case may be reduced and still maintain a safety level close to that of the Tee-profiles.

It should be noted that the results of this investigation require further considerations on important topics such as e.g. corrosion and imperfections.

The aim of this calibration was mainly to study the performance of the buckling rules. It is seen that the analytic results for the buckling rules gives a band of reliability indices for the described reliability limit state. Such results may also be used to chose a target reliability level for direct use of reliability analyses in design.
CONCLUSIONS

The development towards more optimized ship design and the availability of more advanced methods requires attention from the classification societies. The local criteria in the rules must be updated according to new information and advances in computational methods.

A reliability based formulation of the buckling capacity in deck panels have been applied to study the performance of the DnV rules against more advanced formulations. For Tee-profiles results show that the performance is excellent within the range of geometrical proportional typical for tankers.

The demonstrated reliability based calibration method developed by DnV enables to extract the state of the art knowledge from advanced methods into the rules.

The calibration also enables use of the applied reliability formulation as an equivalent requirement to the rules.

ACKNOWLEDGMENT

The opinions expressed herein are those of the authors and should not be construed as reflecting the views of their companies. The results presented herein are mainly from the DnV PROCLASS project.

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RELIABILITY FORMULATION

Collect data for input variables - strengths, loads, etc.

Model the uncertainties and limit states.

Choose target values $\beta_{T,j}$ for each type of failure, and possibly a minimum acceptable $\beta_{min,j}$.

RULE FORMULATION

Define type of structures covered by the rules and other explicit limitations (scope).

Decide the design rule format, fixed fractiles and parameters to be calibrated, e.g. the safety factors.

Choose a range of design parameters to cover the scope of the design rule and estimate frequency of occurrence.

PROBAN-4:

1. Compute the structural design parameters according to the design rule and safety factors.
2. Compute the reliability index $\beta_i$ for the limit states and calculated design parameters.
3. Compute the error according to the penalty function and decide improvements until convergence.

Figure 4. Scheme for optimization of design rules.

Figure 5. Penalty function applied in calibration.
### Table 1. Input variables to the reliability analysis

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<th>No.</th>
<th>Description</th>
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<th>st.dev.</th>
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<td>Global stiffener Imperf. (mm)</td>
<td>LOGNO</td>
<td>10.</td>
<td>1.5</td>
</tr>
<tr>
<td>18</td>
<td>Side/tors. stiff. imp. (mm)</td>
<td>LOGNO</td>
<td>10.</td>
<td>1.5</td>
</tr>
<tr>
<td>19</td>
<td>Local plate imperf. (mm)</td>
<td>LOGNO</td>
<td>4.</td>
<td>1.79</td>
</tr>
<tr>
<td>20</td>
<td>Yield stress (N/mm2)</td>
<td>LOGNO</td>
<td>405.</td>
<td>32.4</td>
</tr>
<tr>
<td>21</td>
<td>Youngs modulus (N/mm2)</td>
<td>FIXED</td>
<td>2.1e5</td>
<td></td>
</tr>
</tbody>
</table>

*) Chosen to simulate a number of designs, See Tables 2 and 3.

### Table 2. Before and after calibration Tee-profile stiffeners

<table>
<thead>
<tr>
<th>scaling factors</th>
<th>( \gamma_1 )</th>
<th>( \gamma_2 )</th>
<th>( \gamma_3 )</th>
<th>( \gamma_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>des no</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>t</td>
<td>h</td>
<td>( t_w )</td>
<td>b_f</td>
<td>t_f</td>
</tr>
<tr>
<td>1</td>
<td>15.89</td>
<td>296.81</td>
<td>27.95</td>
<td>275.77</td>
</tr>
<tr>
<td>2</td>
<td>15.89</td>
<td>293.95</td>
<td>27.63</td>
<td>133.98</td>
</tr>
<tr>
<td>3</td>
<td>16.03</td>
<td>280.10</td>
<td>22.76</td>
<td>103.44</td>
</tr>
<tr>
<td>4</td>
<td>16.56</td>
<td>448.96</td>
<td>15.13</td>
<td>149.19</td>
</tr>
<tr>
<td>5</td>
<td>16.19</td>
<td>393.92</td>
<td>18.07</td>
<td>137.30</td>
</tr>
<tr>
<td>6</td>
<td>15.89</td>
<td>500.00</td>
<td>12.00</td>
<td>252.80</td>
</tr>
<tr>
<td>7</td>
<td>15.89</td>
<td>488.29</td>
<td>18.37</td>
<td>122.47</td>
</tr>
<tr>
<td>8</td>
<td>15.89</td>
<td>355.99</td>
<td>21.38</td>
<td>186.09</td>
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<tr>
<td>9</td>
<td>16.58</td>
<td>492.74</td>
<td>14.33</td>
<td>180.36</td>
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<tr>
<td>10</td>
<td>15.89</td>
<td>394.17</td>
<td>30.00</td>
<td>299.99</td>
</tr>
<tr>
<td>11</td>
<td>15.89</td>
<td>205.82</td>
<td>17.50</td>
<td>272.66</td>
</tr>
<tr>
<td>12*</td>
<td>16.01</td>
<td>225.75</td>
<td>27.26</td>
<td>128.21</td>
</tr>
</tbody>
</table>

*) designs with the lowest weight

### Table 3. Low weight flat bar panels using optimized scaling factors

<table>
<thead>
<tr>
<th>des.no</th>
<th>t</th>
<th>h_w</th>
<th>t_w</th>
<th>c_i</th>
<th>c_val</th>
<th>wgt</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>17.46</td>
<td>303.74</td>
<td>21.54</td>
<td>3</td>
<td>0.0</td>
<td>0.9613</td>
<td>3.114</td>
</tr>
<tr>
<td>5</td>
<td>16.42</td>
<td>300.18</td>
<td>22.85</td>
<td>3</td>
<td>0.0</td>
<td>0.9342</td>
<td>3.381</td>
</tr>
<tr>
<td>7</td>
<td>16.11</td>
<td>296.50</td>
<td>25.40</td>
<td>1</td>
<td>0.0</td>
<td>0.9512</td>
<td>3.544</td>
</tr>
</tbody>
</table>
Cost effective life-cycle design of fatigue sensitive structural components
M.L. Kaminski

Abstract
The paper describes the theoretical backgrounds and presents the preliminary results of a numerical tool for cost effective design of fatigue sensitive structural components for their total or remaining life-cycle.

The method is similar that proposed by Madsen et al and is based on a reliability analysis of crack growth for which the Paris-Erdogan relation is assumed. The planned inspections with their qualities and a repair strategy are accounted for. This is done by applying a system reliability analysis on an imaginary system which represents all logically connected events leading to the failure.

The cost associated with the risk of failure is estimated by the product of the probability of failure and the cost due to failure. The maintenance cost consists of the inspection cost being a function of the inspection quality, and the cost associated with the repair which is estimated by the product of the probability of repair and the cost of repair.

1. Introduction
Ships and offshore structures represent very large capital investments, have large variety of types and are usually one-off designs. They are subjected to severe environmental actions which are predictable with a high degree of uncertainty. They are difficult and expensive to maintain, have extremely high downtime costs of about 20,000 $/day for ships and one order higher for offshore structures. Furthermore, they are prompt to human errors and are subjected to the public's hypersensitivity to their accidental events. In addition, the average age of the world fleet is increasing and is now 17 years. It is reasonable to forecast that the market will require the services of the existing world fleet for a number of years to come. For offshore structures extended lifetime seems to be the challenge of the present decade. It is becoming clear that for instance North Sea platforms designed for a lifetime of about 25 years, may have to continue to serve for considerably longer periods. Hence the operation of marine structures, especially above their design lifetime, posses a
significant challenge with respect to Inspection, Repair and Maintenance (IRM).

The goal of IRM is not to increase the reliability of structure, but to guarantee that the defined safety level is maintained. In this respect, standard IRM procedures, carried out at fixed intervals as required by present design codes, can increase the reliability of the structure over the required level. It may also happen that the standard procedures do not guarantee the defined safety level, and that a special IRM procedure has to be followed.

Terotechnology, as an interdiscipline which is a combination of management, financial, engineering and other practices applied to physical assets in pursuit of economic life cycle cost, i.e.: design, construction, service and demolition costs, emphasizes that IRM should be defined already at the design stage where important system properties are determined. One of these properties is the resistance to ageing, i.e.: the resistance to technical deterioration.

Fatigue as the main reason of ageing is treated as the most crucial consideration in the strength design of a welded steel offshore structure. This can be found back in service experience in offshore, which indicates that serious accidents are caused by fire, explosions and blowouts and not by structural collapse. As far as fatigue damage is concerned, with the exception of a few "nasties", fatigue performance is generally very good. The other reasons, beside "fatigue-phobia" in the design stage, are thought to be related to a general overestimate of design loads in current practice and to the generally high standards of design, construction and maintenance adopted by the offshore industry itself and/or in response to regulations of governmental bodies.

Learning about serious accidents of ships from service experience is limited. This because ships in contrary to offshore structures often disappear after serious accidents. Nevertheless, ship's disappearances are thought to be attributed to a combination of brittle fracture and fatigue and additionally to explosions in case of tankers. In general, ship industry adopts less stringent standards of design, construction, maintenance and verification, but this is to some extent compensated by the fact that ships are more redundant than offshore structures.

In spite of substantial experimental research, a designer still has to do with a large scatter of fatigue data. However, even in the case of exactly predictable fatigue behaviour, a design which assures a certain safety level during a whole life of structure may lead to impractical
solutions. Therefore, fatigue is sometimes treated as an inherent property.

All the above implies that in order to keep a certain safety level, the structure has to be inspected and if necessary repaired during its life. Inspection, repair and risk of failure of a structure involve substantial costs which interact with the initial cost of design and production. An optimum design may be defined as a design which minimizes the total life-cost of a structure.

Hereafter, a method is outlined which makes cost effective life-cycle design of fatigue sensitive structural components possible. The method is similar to that proposed by Madsen et al., and in general, is based on a reliability analysis of a crack growth for which the Paris-Erdogan relation is assumed. The inspections and repair strategy are accounted for by applying a system reliability analysis on an imaginary system which represents all logically connected events leading to the failure.

Before that, let consider briefly the notions “safety”, “accident” and “failure”. Safety is “control of accidental loss”. This includes both preventing accidents and keeping losses to a minimum when accidents do occur. An accident is “an undesired event that results in harm to people, damage to property or environment and loss of production or transport capability”. An accident may be caused by failure which is lack of the performance. Fatigue, ductile collapse or corrosion may for instance lead to failure. This consideration is crucial for selecting the mathematical definition of failure and costs which contribute to the cost of failure. Both elements should be compatible.

2. Life-cost model

The following costs are assumed to contribute to the total life-cycle cost $C_T$. First, the initial cost $C_0$, which consists of the design, construction, transportation and installation costs. Then, the maintenance cost which consists of all inspection costs $C_{i1}$, and all repair costs $C_{ri}$. Finally, the cost associated with the risk of failure. It is also possible to include positive or negative demolition cost and the rate of interest.

The initial cost is assumed to be a function of component scantlings $z_1$ and the production quality $q_p$. The production quality is assumed to be a product of the assemblage quality $q_e$, the welding quality $q_w$, and the post-welding treatment quality $q_t$. The assemblage quality is measured by the inverse of appropriate tolerance, for instance the allowable misalignment, and the welding quality is measured by the
The crack initiation and growth are the main reasons for technical deterioration of structures. The crack initiation is left out of the scope of the present work. The argument for that is that initial cracks in welded structures are always present and it is assumed for the time being that
only such cracks can grow and may consequentially lead to a
failure and then possibly to an accident. Of course, cracks
can also initiate at places where stress concentration are
high. After that, these cracks can easily become dominant.

The conventional S-N approach is not suitable for
reliability analysis of fatigue in combination with IRM
because the governing information being the crack length is
hidden in this approach. The fracture mechanics is well
suitable.

In the present work the simple, one-dimensional and linear
model of the crack growth defined by the Paris-Erdogan
relation is assumed:

\[
\frac{da}{dN} = C (\Delta K)^m, \quad \Delta K > \Delta K_{th}, \quad a_{N=0} = a_0
\]  

(2)

The left hand side gives the crack length increment in one
stress cycle with stress intensity factor range at the crack
tip \(\Delta K\). \(C\) and \(m\) are material factors. \(\Delta K\) is expressed as:

\[
\Delta K = Y(a) \sqrt{\pi a} S
\]  

(3)

where \(Y(a)\) is the geometry function depending on the overall
geometry of the joint including the presence of the weld,
and \(S\) is the range of a far-field reference stress.

The discussion of associated assumptions and transformation
of relations (2) and (3) into the integral form is omitted
here, because it is well established and can be found in
literature. The integral form of (2) is as follows:

\[
\int_{a_{beg}}^{a_{end}} \frac{da}{(Y(a) \sqrt{\pi a})^m} = C \nu (T_{end} - T_{beg}) A^m \Gamma \left(1 + \frac{m}{B}\right)
\]  

(4)

\(G(a)\) is the auxiliary function:

\[
G(a) = 1 - \frac{\Gamma \left(1 + \frac{m}{B}; \left(\frac{\Delta K_{th}}{Y(a) \sqrt{\pi a}}\right)^B\right)}{\Gamma \left(1 + \frac{m}{B}\right)}
\]  

(5)
which allows for the threshold effect (stress range intensities at the crack tip lower than \( \Delta K_{thr} \) do not contribute to the crack growth, for steel \( \Delta K_{thr}=300 \text{ Nmm}^{-3/2} \)).

\( \Gamma(x) \) is the gamma function, and \( \Gamma(x;p) \) in the numerator of (5) is the incomplete gamma function \( \Gamma(x;p)=\int_0^p (e^{-t}t^{x-1}) dt \). \( v \) is the number of stress cycles per unit time. A and B are parameters of the Weibull distribution, which is assumed to describe the long term far-field stress range distribution:

\[
F_S(s) = 1 - e^{-\frac{s}{A}}, \quad s > 0
\]

The left hand side of relation (4) represents the resistance \( R \) of a joint against crack growth from the crack length \( a_{beg} \) at the beginning of the loading till a given crack length \( a_{end} \). The right hand side represents the loading \( L \) imposed on the joint between the time \( T_{beg} \) and a given time \( T_{end} \).

4. State function

The state function is defined as:

\[
g = R - L
\]

and is a function of the set of variables:

\[
g = g(a_{beg}, a_{end}, T_{beg}, T_{end}, V)
\]

where \( V \) contains, in general, the following variables:

\[
V = \{ A, B, m, C, v, \Delta K_{thr}, Y, \ldots \}
\]

The set of variables in the state function can be subdivided into two sub-sets: deterministic \( D \) and stochastic \( X \):

\[
g = g(X, D)
\]

This subdivision is arbitrary. In general:

\[
X = \{ a_{beg}, a_{end}, A, B, m, C, Y_j \}
\]

\[
D = \{ T_{beg}, T_{end}, v, \Delta K_{thr} \}
\]

The state function is universal. Its physical interpretation depends on of the first four variables in (9).
Hereafter, it is outlined how to use the state function (9) for calculation of the probability of failure including inspection and repair. For the sake of simplicity, two inspections are assumed and the repair strategy is such that all detected cracks are repaired.

5. Probability of failure

One physical component with one state function (9) is considered. The first four variables in (9) are as follows: the initial crack size, the critical crack size, the initial time, and the time. At each time there is a certain probability that the component will fail. This is because some variables in (9) are uncertain. The probability of failure can be calculated by the componental reliability software, e.g.: COMREL (a part of STRUREL).

The act of inspection complicates the situation. First of all, when during the inspection no crack is detected it does not necessarily mean that no crack is present. A crack may be in fact only detected by a certain probability depending on the size of the crack and on the inspection method, while cracks shorter than a certain size are not detectable at all by ordinary methods. For crack detection under water, it is claimed that there is a 90% probability of detecting a 45 mm long crack with the use of MPI (Magnetic Particle Inspection). However, to detect a crack with the same probability with VI (Visual Inspection) requires a crack length of 225 mm. The probability of crack detection is calculated in the same way as the probability of failure before the first inspection. Namely, by calculating the probability that the crack has grown longer than the detectable crack size. This is made using the same state function (9). But in this case \( a_{\text{end}} \) is the detectable crack size and not the critical crack size as it was in the case of calculation of the probability of failure.

A second complication caused by the act of inspection is that there are more possibilities leading to a failure (at least \( 2^n \)). Therefore, a systematic approach is necessary. This is done by creation of an imaginary system which is shown on figure 1, and which consists of components which are defined in table 1.

Now, the problem of calculating of the probability of failure is as follows. The state of a system is defined by a set of state functions describing the components or failure modes of the system \( A_j \). In the present problem the limit functions of all components have the same form (9). The difference between the limit functions of the various components is the different meaning of the first four
variables in (9). The components are arranged in a logical representation which connect the components by "And-gates" and "Or-gates" in a fault tree (figure 1) with system failure as its top event. All state functions in the system are a function of common set of variables some of which are uncertain. These uncertain variables $X$ (12) called basic variables are random with joint distribution function $F_X(x) = P(\cap_{i=1}^{n} (X_i \leq x_i))$ defining the stochastic model. The individual state function, denoted by $g_j(X)$, is defined such that $g_j(X) > 0$ corresponds to favourable states of the $j$-component in the system. $g_j(X) = 0$ denotes the so-called limit state or the failure boundary, and $g_j(X) < 0$ defines the failure domain of the $j$-component. The logical connection of the system components has an equivalent representation in the connection of the failure domains $F_j$. An "Or-gate" defines the union of componental failure domain (series system): $F_{ser} = \cup_{i=1}^{n} (F_i)$. An "And-gate" defines the intersection union of failure domain (parallel system): $F_{par} = \cap_{i=1}^{n} (F_i)$. An arbitrary logical arrangement of components in a coherent fault tree can always be represented in terms of a minimal cut-set system, which is the union of intersections of failure domains $F_{sys} = \cup_{i} \cap_{j} (F_{ji}) = \cup_{i} \cap_{j} (g_{ji} \leq 0)$. This representation should be minimal in the sense that no combined set contains another as a genuine subset. The formation of such a set can always be achieved by the systematic application of the distributive and the absorption rules of set algebra (figure 1). The probability of failure is defined as:

$$P_f = P(X \in \{F_{sys}\}) = \int_{F_{sys}} dF_X(x)$$

SYSREL which is a part of structural reliability software STRUREL provides an approximate solution for $P_f$.

The fault trees which appear in the present problem contain the complementary events, i.e.: $A_i$ and $\overline{A_i}$ such that $A_i \cup \overline{A_i} = 1$ and $A_i \cap \overline{A_i} = 0$. CUTALG (an utility of STRUREL) can not reduce such fault trees into minimal cut-sets. Such systems can be reduced by hand by the application of the rule: $A \cup (\overline{A} \cap B) = A \cup B$. The result of such reduction is shown on figure 1.

6. Example

The numerical tool is under development, and is not yet fully operational. The author hopes to show during the presentation results of an example which includes costs calculation.
Table 1. Definition of components

<table>
<thead>
<tr>
<th>i</th>
<th>State function</th>
<th>$A_j=$</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$g_1=g(a_o, a_c, T_o, T_1)$</td>
<td>$g_1&lt;0$</td>
<td>failure before 1st insp</td>
</tr>
<tr>
<td>2</td>
<td>$g_2=-g_1$</td>
<td>$A_2=A_1$</td>
<td>complementary to 1</td>
</tr>
<tr>
<td>3</td>
<td>$g_3(a_o, a_d1, T_o, T_1)$</td>
<td>$g_3&lt;0$</td>
<td>detection at 1st insp</td>
</tr>
<tr>
<td>4</td>
<td>$g_4=-g_3$</td>
<td>$A_4=A_3$</td>
<td>complementary to 3</td>
</tr>
<tr>
<td>5</td>
<td>$g_5(a_{r1}, a_c, T_1, T_2)$</td>
<td>$g_5&lt;0$</td>
<td>failure after 3</td>
</tr>
<tr>
<td>6</td>
<td>$g_6(a_o, a_c, T_o, T_2)$</td>
<td>$g_6&lt;0$</td>
<td>failure after 4</td>
</tr>
<tr>
<td>7</td>
<td>$g_7=-g_5$</td>
<td>$A_7=A_5$</td>
<td>complementary to 5</td>
</tr>
<tr>
<td>8</td>
<td>$g_8=-g_6$</td>
<td>$A_8=A_6$</td>
<td>complementary to 6</td>
</tr>
<tr>
<td>9</td>
<td>$g_9(a_{r2}, a_d2, T_1, T_2)$</td>
<td>$g_9&lt;0$</td>
<td>detection at 2nd insp after 7</td>
</tr>
<tr>
<td>10</td>
<td>$g_{10}=-g_9$</td>
<td>$A_{10}=A_9$</td>
<td>complementary to 9</td>
</tr>
<tr>
<td>11</td>
<td>$g_{11}(a_o, a_d2, T_1, T_2)$</td>
<td>$g_{11}&lt;0$</td>
<td>detection at 2nd insp after 8</td>
</tr>
<tr>
<td>12</td>
<td>$g_{12}=-g_{11}$</td>
<td>$A_{12}=A_{11}$</td>
<td>complementary to 11</td>
</tr>
<tr>
<td>13</td>
<td>$g_{13}(a_{r2}, a_c, T_2, T_3)$</td>
<td>$g_{13}&lt;0$</td>
<td>failure after 9</td>
</tr>
<tr>
<td>14</td>
<td>$g_{14}(a_{r1}, a_c, T_1, T_3)$</td>
<td>$g_{14}&lt;0$</td>
<td>failure after 10</td>
</tr>
<tr>
<td>15</td>
<td>$g_{15}(a_{r2}, a_c, T_2, T_3)$</td>
<td>$g_{15}&lt;0$</td>
<td>failure after 11</td>
</tr>
<tr>
<td>16</td>
<td>$g_{16}(a_o, a_c, T_o, T_3)$</td>
<td>$g_{16}&lt;0$</td>
<td>failure after 12</td>
</tr>
</tbody>
</table>

The present example illustrates the capability of the tool in reliability calculation of a fatigue sensitive joint including inspections and repairs.

The physical problem is a centrally cracked panel. The panel is made of steel, which has stochastic constants of crack growth $lnC$ and $m$. The effect of corrosion on fatigue is modelled by assuming $\Delta K_{thc}=0$. The panel is cyclically loaded.
from an initial time $T_0$ till a final time $T$, with $v$ cycles per year. The amplitude of the loading is a stochastic value defined by the Weibull distribution of two parameters $\ln A$ and $1/B$, which are also stochastic. In the panel at time $T_0$ there exists an initial crack which has an uncertain length $a_c$. The failure is defined when the crack length reaches the critical crack length $a_e$, which is also uncertain. The geometry function is assumed constant. The stochastic model is summarized in Table 2.

Two cases are calculated. Case I - two visual inspections, with the same quality $q_I=0.23$, at $T_1=10$ and $T_2=20$ years. Case II - one MPI inspection with the quality $q_I=1.3$, at $T_1=10$ years. In both cases all detected cracks are repaired.

Table 2. The stochastic model

<table>
<thead>
<tr>
<th>Sym.</th>
<th>Variable name</th>
<th>Unit</th>
<th>Distribution</th>
<th>Mean</th>
<th>Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_0$</td>
<td>initial time</td>
<td>year</td>
<td>fixed</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>$T$</td>
<td>lifetime</td>
<td>year</td>
<td>fixed</td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td>$T_1$</td>
<td>first inspection</td>
<td>year</td>
<td>fixed</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>$T_2$</td>
<td>second inspection</td>
<td>year</td>
<td>fixed</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>$a_c$</td>
<td>initial crack size</td>
<td>mm</td>
<td>exponential</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$a_r$</td>
<td>repair crack size</td>
<td>mm</td>
<td>exponential</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>$a_e$</td>
<td>critical crack size</td>
<td>mm</td>
<td>normal</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>$q_I$</td>
<td>quality of VI</td>
<td>mm$^{-1}$</td>
<td>fixed</td>
<td>0.23</td>
<td>-</td>
</tr>
<tr>
<td>$G_I$</td>
<td>quality of MPI</td>
<td>mm$^{-1}$</td>
<td>fixed</td>
<td>1.3</td>
<td>-</td>
</tr>
<tr>
<td>$a_{\min}$</td>
<td>minimal smallest crack</td>
<td>mm</td>
<td>fixed</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>$\ln A$</td>
<td>Weibull parameter of stress distribution</td>
<td>MPa</td>
<td>normal*</td>
<td>1.6</td>
<td>0.22</td>
</tr>
<tr>
<td>$1/B$</td>
<td>Weibull parameter of stress distribution</td>
<td>-</td>
<td>normal*</td>
<td>1.2</td>
<td>0.15</td>
</tr>
<tr>
<td>$v$</td>
<td>upcrossing rate</td>
<td>cycles</td>
<td>fixed</td>
<td>$1 \times 10^6$</td>
<td>-</td>
</tr>
<tr>
<td>$m$</td>
<td>material parameter</td>
<td>-</td>
<td>normal**</td>
<td>3</td>
<td>0.15</td>
</tr>
<tr>
<td>$\ln C$</td>
<td>material parameter</td>
<td>-</td>
<td>normal**</td>
<td>-29.9</td>
<td>0.5</td>
</tr>
<tr>
<td>$Y$</td>
<td>geometrical function</td>
<td>-</td>
<td>fixed</td>
<td>1.12</td>
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Correlated values: *- $\rho=-0.79$, **- $\rho=-0.9$

Results which are self explaining are shown on figure 3.

7. Conclusions

A procedure for cost effective life-cycle design of fatigue sensitive structural component and in particular reliability calculation of such component including inspections and repairs has been outlined. The reliability calculation has been illustrated by an example.
Figure 3. Results of reliability calculation including inspection and maintenance

Acknowledgements

The paper is based on Nevesbu’s work supported by the research program “Cost Effective Life-cycle design of Robust Floating Structures” sponsored by EEC under the number TH/03284/88. Beside Nevesbu, also MARCON Engineering, RINa and GL participate in the project. The author acknowledges information, comments, and/or his fruitful discussion with Prof. J.J.W. Nibbering, Prof. D. Faulkner, Dr. S. Gollwitzer, Prof. K. Schittkowski, Dr. C. Östergard, Dr. R. Cazzulo and Dr. A.A. Ham. The opinions expressed in this paper are those of the author.

The 150 anniversary note

On behalf of the Nevesbu wherein 90% of all graduates come from the Delft University of Technology, the author would
like to congratulate the University and especially the Division of Naval Architecture, which contributes significantly to the Dutch and the international shipbuilding. Furthermore, on behalf of all those who find a friendly working or studying place at the University during the wind-storms of the history in their home-countries, the author would like to acknowledges the University for its helpful attitude.

Bibliography

The author reviewed many references which are relevant to the subject. Due to limited space only these which mostly affected the author's work are listed below.


Extra margin of safety by the new class notation.  
Dynamic loading approach (DLA) for tankers  
B. Curry

INTRODUCTION

One of the most significant new technical services introduced by ABS to the marine industry during 1991 has been the offering of the Dynamic Loading Approach (DLA) optional class notation for tankers. DLA represents a significant step taken by ABS in the classification of tankers by allowing designers to employ a more explicit engineering approach to determine the expected dynamic loads and permissible stresses acting on a vessel in a seaway versus the traditional semi-empirical approach of the Rules. The use of this dynamic loading approach may possibly result in scantlings (i.e., structural members) that exceed the safety margins specified by the ABS Rules for Building and Classing Steel Vessels. In such cases, ABS will recognize this added optional margin of safety through the additional DLA class notation. Several newbuildings currently being built to ABS class are now being considered for this class designation.

BACKGROUND

To best appreciate the impact of the Dynamic Loading Approach on the traditional scheme of tanker classification, it is important to review the basis of the current ABS Rules for Building and Classing Steel Vessels.

Historically, the ABS Rules for hull structures have been semi-empirically based and presented in tabular form for various design parameters. During the last 20 years this approach has evolved into the empirical formula format of today's ABS Rules with which the maritime industry has become familiar.

The hull scantling requirements contained in the current ABS Steel Vessel Rules have been established in this semi-empirical, manner recognizing that the requirements need to provide for the:

- Nominal loadings acting on the vessel's structures,
- Simplified and easy to apply design equations characteristic of the Rules, and
- Ongoing satisfactory service experience of the Rules in practical application.

Additionally, any criteria pertaining to the assessment of the global or local strength of the vessel's structure, needs to consider three factors which must always be treated together. These are:

- the expected loads acting on the structure,
the analysis method utilized to establish the effects of the expected loads acting on the structure, and

- the extent to which the strength of the structure is permitted to be utilized in resisting the demands placed on it by the expected loads.

The individual hull scantling design equations of the Rules reflect these factors, which are then calibrated, based on satisfactory service experience, to arrive at the final form of the criteria used in the production of reliable vessel structural designs.

**Determination of Dynamic Loads**

In examining the basic components of the design equations, it can be seen that the common element running through the three factors outlined above is the expected loads. This gives rise to the important question at issue — what are the dynamic loads acting upon vessels at sea?

The loads acting on the vessel come from a variety of sources, both internal to the vessel itself as well as those acting on the vessel from the external environment (Figure 1). The ship motions experienced by the vessel at sea are generated by the external dynamic wave loading acting on the vessel (Figure 2). This loading is comprised of components such as the wave-induced bending moments and shear forces, along with the external wave pressure acting on the hull exterior. Just as
important are the wave-induced loads acting on the interior of the vessel. In the case of tankers, these loads are primarily a result of liquid cargo weight and movement acting on the cargo tank boundaries. Figure 3 shows a graphical representation of this cargo loading for an extreme example of checkerboard loading in a double hull tanker, where the outboard cargo tanks are empty adjacent to a fully loaded center cargo tank.

**Special Considerations for Tankers**

In examining the dynamic loads acting on vessels, it is important to consider some of the specific concerns for tankers, particularly double hull tankers, which are of interest to the industry today.

For tankers in general, there has been a trend over the last decade to minimize structures in many designs. The result is that these light scantling vessels effectively represent short life designs in practice.

In double hull tankers, due to the double barriers, there is no cancellation of internal and external forces to the extent found in single hull vessels (Figure 4). Therefore, the associated dynamic loads are critical to the design. This is confirmed by the fact that the dynamic loads acting on the structure can in fact be 60% greater than the associated static loads.

![Figure 2](image-url)

**External Dynamic Wave Loading**

---

659
Figure 3
Internal Dynamic Liquid Cargo Loading

Figure 4
Cancellation of Internal/External Forces

Double Hull Tanker

Single Hull Tanker
These special considerations are further key examples as to the importance of the realistic determination of the dynamic loads acting on vessel structures.

**Current Practice**

Over the last decade, the standard practice for the determination of dynamic loads for application to a vessel's structural design can be summarized as follows:

1. The dynamic loads are first approximated by a static load with the addition of a factor.
2. The dynamic load is derived based on service experience without considering the dynamic characteristics of individual vessel designs.
3. The results of this approach yields a generalized loading on vessel structures that are not necessarily oriented to a specific vessel design.

**Uncertainties**

The establishment of the loads acting on the vessel in a realistic manner has long been recognized as the greatest uncertainty in the entire structural design process. This uncertainty stems primarily from:

- trying to determine the magnitude of the individual load components,
- trying to appropriately combine the individual components which are acting simultaneously, and
- trying to simplify the loading problem by idealizing the complex dynamic loads into a form in which they can be utilized as more easily represented static loads.

With current technology and computer based analytical tools, we are now better able to reduce these uncertainties and more accurately model the loads to be used in the design process.

**ABS Rules and Direct Engineering Analysis**

The current hull structure criteria found in the ABS Rules are an appropriate basis for design and can be used directly in establishing a vessel's scantlings and in granting the ABS hull classification symbol A1. However, recognizing the uncertainties in the loads as mentioned above, a designer may elect to pursue the design in a more sophisticated and comprehensive manner utilizing available analytical methods. When a designer adopts this approach for the design, the permissible stresses found in the present Rule requirements are allowed to be increased, since the analytical approach eliminates some of the load uncertainties which are compensated for in the margins built into the Rule criteria.
When the basis of establishing the loads used in the design is changed from the empirical Rule scantling equations to that of the analytical approach, the scantlings can also change. In some cases, the results of the analytical approach lead to an increase in some scantlings. However, there is no recognition of this occurrence by ABS as the designer can also reduce some scantlings below the direct Rule equations where permitted by the analysis.

**DYNAMIC LOADING APPROACH**

The optional class notation for tankers, the Dynamic Loading Approach, is primarily an outgrowth of the last point made above. The whole principle of the Dynamic Loading Approach is based on the idea of giving recognition to the fact that direct analytical calculations can lead to more conservative scantlings. However, while recognizing these potential increases in scantlings, the key to DLA is that it allows no decreases in scantlings below those that are obtained from direct application of the individual Rule equations found in present ABS Steel Rules. Therefore, utilization of the approach assures conservatively biased scantlings for a tanker design. Since this approach will lead to certain scantlings that exceed the intended safety margins of the Rules, it is appropriate to recognize this added optional margin of safety by the use of an additional classification notation "DLA".

**What DLA Signifies**

When the additional class notation of DLA is requested for a tanker design, it signifies that:

1. The design is based on an analysis which more realistically considers the loads acting on the structure and the dynamic nature of the loads, and
2. in no instance is a design scantling derived from the results of the detailed analysis to be less than that obtained from other requirements in the current Rules.

**Technical Guidance**

The technical guidance to be used by designers in use of the Dynamic Loading Approach is now available from ABS upon request. This guidance presents the:

1. specification of the loads,
2. manner of load component combination,
3. approaches used to establish the load effects in the structure, and
4. permissible stress to be used.
Overview of DLA Procedure

The following is a brief overview of the procedure utilized in applying the Dynamic Loading Approach in the design of tankers. The procedure is also presented in graphical form in Figure 5.

Wave Environment

The primary inputs to the Dynamic Loading Approach are the geometry and structure of the vessel under consideration, coupled with a description of the environment in which the vessel is intended to operate. If the operation of the vessel is not route-specific -- i.e., the vessel is intended for unlimited worldwide service -- the wave statistics for the North Atlantic Ocean should be utilized. The wave input to the analysis is in spectral form which can be based on either measured data or appropriate mathematical formula.

Ship Dynamic Response

To determine the dynamic response of the vessel, a sea-keeping analysis is performed utilizing an appropriate method, such as linear strip theory. The geometry of the hull must be modeled in the applicable mathematical form. The
motion and load characteristics of the vessel are then calculated for a range of load cases, vessel headings and speed – all of which are specifically outlined in the DLA Guidance.

**Dynamic Loading**

Taking these motion and load characteristics in concert with the realistic wave statistics, the component dynamic loads are determined. These include the loads stemming from the action of the external waves, the motion induced loads, as well as the loads produced from internal sources such as liquid cargo motions.

In order to consider the dynamic loading over the life of the vessel, a probabilistic approach is employed to determine the long term extreme values for each of the load cases considered.

One of the key elements of the Dynamic Loading Approach is the method established to apply the simultaneously occurring combined loads from the above analysis to the structural model. The details of this method are presented in the DLA Guidelines. The combined dynamic loads are then applied, together with static loads, in the structural analysis along with the distribution of the external hydrostatic and hydrodynamic pressures over the hull. The structure is, therefore, in a dynamic equilibrium condition with these applied loads.
Structural Response

The structural adequacy of the tanker hull is examined through the use of the finite element method (FEM) approach. A three-dimensional (3-D) coarse mesh model is used to represent the hull girder structure (Figure 6) and two-dimensional (2-D) fine mesh models are to be used for local structures. The results of the 3-D FEM analysis yield the hull girder's overall response and are used as input for the 2-D FEM analysis. The 2-D FEM analysis is used to determine the more detailed local stresses. The local structures to be considered include transverse web frames (Figure 7), longitudinal girders, and all horizontal stringers.

Strength Evaluation

In evaluating the results of FEM analyses, the stresses and deflections in the structure are examined to determine if they fall within the prescribed limits of the failure modes of yield and buckling specified in the DLA Guidance. An assessment will also be done based on separate ABS guidance on this topic.
CONCLUSIONS

In conclusion, the new Dynamic Loading Approach optional class notation for tankers assures that a tanker will be designed and built considering:

- realistic motion characteristics of the vessel,
- realistic dynamic load distribution on the hull structure,
- increased scantlings, where needed, in the local structure, and
- no reductions to existing Rule scantlings.

All of these characteristics contribute to stronger, more robust and longer-life vessels.

A tremendous amount of interest has been expressed in DLA. To date, ABS has completed several analyses on behalf of clients applying for the DLA notation, and many more are pending.

In the long term, the same engineering philosophy used to develop the ABS Dynamic Loading Approach is being used in a major ABS research project commenced in 1990, to revise the hull design criteria in the ABS Steel Vessel Rules. ABS anticipates that future revisions to its Rules will be increasingly influenced by the Dynamic Loading Approach.
Safety of bulk carriers

J.M. Ferguson

Over the past year Lloyd's Register has endeavored to provide the shipping community with an awareness of bulk carrier losses and the probable reasons for such. Single hull bulk carriers are ships which have developed in size to today’s 'Cape' size ships, over a very short period of time, in association with the use of higher tensile steels and the optimisation of structural arrangements to suit both cargo handling and construction. Loadings on these almost open type ships are very complex and in addition to longitudinals bending and local cargo induced stresses the structural configurations employed result in significant torsional/warping stresses. In addition the vertical cargo loading results in significant transverse stresses in the deck platings between the hatchways. These transverse loadings are particularly sensitive to overloading of cargo.

During the loading/unloading of cargo the ship can be subjected to physical abuse which can result in damage to the structure. Certain cargoes, such as high sulphur coals, can also create high levels of both localised and general corrosion in short periods of time. Awareness of the potential problems is therefore important by all parties concerned.

This paper addresses many of the problems and the actions to be taken.
Introduction

During the year 1990, twelve ships carrying dry bulk cargoes, where structural failure may have been a factor, were lost with a consequent loss of life of a reported 200 seamen. Of the ships concerned eight were bulk carriers, two were ore carriers and two were ore or oil carriers. For ease of reference the structural cross section for each type is shown in Figure 1. A number of major structural failures to the primary hull girder members on bulk carriers which did not result in the loss of the ships also occurred during this period.

In the cases of the ships that were lost and also in the cases where major structural damage occurred without loss the ships concerned were generally carrying iron ore.

During 1991 thirteen ships with bulk carrier structural configuration have gone missing with additional loss of life. The majority of these ships were again carrying iron ore.

This year, to end of March, 1992, one ship has sunk and four others were reported as damaged, having leakages and fractures.

The purpose of this paper is to give an awareness of what LR has done, or is doing at this time with regard to addressing the situation regarding bulk carrier incidents as well as taking the opportunity to discuss the matter as a whole.
Other aspects such as the greater usage of higher tensile steels in recently constructed ships also make this a time for deliberation with regard to this ship type.

It has become increasingly apparent that dry bulk carriers are the heavy workhorses of the world fleet and because of their cargoes could inadvertently experience loadings not normally catered for in their design. The growth in size of these ships and the proposals for the use of higher yield steels has necessitated that a more or less continual review of their scantlings takes place, taking account of both service experience and findings from theoretical investigations. Recent events, however, in the form of major damage to a number of bulk carriers some of which were constructed in the last decade led Lloyd’s Register’s Chief Ship Surveyor to giving priority to a study with a view to determining the probable causes of incidents to this ship type.

A brief chronology of events which illustrate Lloyd’s Register’s recent concern with regard to bulk carriers is given as follows:

February ’89 - LR special instruction to surveyors on survey of topside tanks and holds.

November ’90 - Commencement of bulk carrier investigation.

November ’90 - LR special instructions to surveyors on survey of holds, in particular main frames and brackets.

December ’90 - Press release by LR advising of corrosion and cracking problems.

January ’91 - Additional guidance to surveyors on survey of bulk carriers.

January ’91 - Letter to bulk carrier operators/owners portraying concern and requesting information.

February ’91 - Further letter to owners of bulk carriers drawing attention to untypically high rate of casualties and advising of LR policy.

April ’91 - Close up inspection requested on sample of bulk carriers as part of LR investigations.
May '91 to date - Lectures and Seminars worldwide advising the shipping community about the problems encountered on Bulk Carriers, as seen by LR.

June '91 - Further guidance to Surveyors on the survey of cargo hold spaces on Bulk Carriers.

October '91 - LR Brochure, Bulk Carriers: guidance to operators on the inspection of cargo holds.

November '91 - LR Technical Committee agreed new Rule Requirements for enhanced scantlings of Bulk Carrier's cargo holds, side frames and transverse water tight bulk heads.

These actions can be summarised as both providing guidance to LR surveyors and being a vehicle to provide the shipping community with an awareness of potential problems with this ship type. The letter to the shipowners dated January '91 as well as indicating LR's concern also constituted a questionnaire. This was sent out to a large sample of bulk carrier owners and many have responded positively with information. In addition to this a more general letter was also sent out to bulk carrier owners worldwide during February advising them of the study being carried out. This letter also requested any information considered relevant to be forwarded to LR's Technical Planning Department in the Ship Division. A copy of these letters, together with the Press release and the guidance brochure are included in Appendix 1.

In investigating the various levels of the problem, from design to operation, it appears that many operators believe that cracking in the structure of these ships is inevitable, possibly as a result of poor design or detail, and more probably as a result of operational procedures.

This was the challenge that Lloyd's Register was addressing with a view to making the occurrence of cracking and unacceptable levels of structural depreciation a rare event and thereby improving reliability of the ships concerned. To do this it was recognised that a better appreciation of the operators operational pressures was fundamental, together with a reappraisal of structural arrangements and survey requirements.
Initial Work

In the first instance, a five point plan was devised in order to produce a rational and measured short-term response to the main problem, if it could be identified. This plan, was also to define possible areas of work which, when completed, could have a positive effect on structural and operational safety of bulk carriers.

Five point plan:
1. Casualty and damage investigation.
2. Relevant information from operators.
3. Visits to ships during unloading/loading process.
4. Preparation of initial Rule proposals.
5. Commencement of relevant full scale measurements.

The first three points were essentially information gathering and were extremely important. The discussions with a limited number of extremely helpful operators and associated visits to their ships, particularly during the unloading process, were used to concentrate our thoughts and define the areas for further study.

It soon became clear that, whilst there are many factors which affect a bulk carriers’ structural or operational capability, they are a well tried design and will perform satisfactorily provided the structure does not significantly deteriorate locally due to corrosion, physical damage or overloading.

Aspects which can influence the life of bulk carriers are shown in Figure 2 and include structural design, ship operation, cargo handling aspects, types of cargo and maintenance and repair policies. These topics are generally addressed in this paper although not necessarily under these specific headings. A summary of aspects addressed is given as follows:

i) What is a bulk carrier, its cargoes and its environment.
ii) Age structure of the fleet
iii) Statistics of losses
iv) Focal points of damage
v) Development of damage
vi) Conclusions
What is a Bulk Carrier, Its Cargoes and Its Environment?

The most widely recognised structural concept identified with a bulk carrier is a single deck ship with a double bottom, hopper tanks, single transversely framed side shell, topside tanks and deck hatchways. This concept, as described, dates back to the early nineteen sixties when deadweights of up to about 20,000 tons were introduced. During the period until the early nineteen seventies this design configuration was extended to ships of about 170,000 tons deadweight. During the mid sixties the utility of the ship type was further developed when the O.B.O. (Ore, bulk, Oil.) ship was conceived. This development in operational capabilities came after considerable investigation which concluded that this ship type could carry liquid oil cargoes without destroying the basic simple structural concept. An outline structure arrangement for the cargo area of a bulk carrier is shown as Figure 3.

Cargoes carried by these ships are numerous, however, for the purpose of this paper, discussion will be on the carriage of ores and coals.

In a practical sense the shipowner endeavours to minimise the empty ballast voyage legs of the operational cycle with these ships. With regard to the
carriage of coal the major exporters and major consumers dictate the trade plied by bulk carriers. Major producers of coal for seaborne export include Australia, United States and South Africa and the total coal carried in ships is over 300 million tonnes per year. Major importers of coal are Japan and Europe as well as other industrial nations such as Korea and Taiwan. A typical voyage route for a ship upon leaving Europe could be a ballast trip to the United States for loading of a particular coal cargo, followed possibly by loading of another parcel of coal in South Africa and a voyage to Japan. After discharge in Japan the ship could then proceed to Australia for a cargo of coal or even ore for delivery to Europe. During this service a wide variety of coal cargoes, sea and environmental conditions as well as port operational procedures will be experienced.

In the carriage of ore, which is the most severe cargo carried in terms of loading on the ship, the ships ply between the major exporters e.g. Brazil, Australia, India, South Africa and Canada, and the major consumers e.g. Japan, Europe, Korea etc.
Due to its high weight per unit volume, ore is normally carried in alternate holds within the ship. In general the holds loaded are the odd numbers i.e. nos. 1, 3, 5, 7 etc. The purpose of this alternate loading is to increase the height of the ships centre of gravity above the base so as to make the ship less stiff. i.e. the ships roll motions are more moderate. Even with the ore cargoes carried in alternate holds the cargo quantity does not occupy, in many occasions, a large proportion of the hold space.

In addition to commercial pressures dictating the growth in the ship size for the carriage of ore and coal they have also dictated that the cargoes can be loaded and unloaded from the ships holds as quickly as possible. In order that this can be attained ports have developed more efficient facilities in terms of grab size for discharge and conveyor systems for loading. In this respect grab sizes have greatly increased in capacity and in unloaded weight. Indeed it is now common for unloaded grabs to weigh as much as 35 tons. Examples of typical weights for unladen grabs are given as follows with their respective ports. Equipment to free coal or even ore from the ship structure can constitute hydraulic hammers fitted to the extending arms of tractors within the holds. In addition, the gathering of coal or ore in the holds can be the job of bulldozers which are, to say the least, ship unfriendly. A fundamental question to be addressed is; “can a ship be designed to withstand the repeated energy from 35 ton grabs or bulldozers when used with enthusiasm?” ... If traditional shipbuilding standards are to be employed probably not.

<table>
<thead>
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<th>Iron Ore</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emo Maasvlakte</td>
<td>20/36 18/28 (Tons)</td>
</tr>
<tr>
<td>Redcar</td>
<td>10/15 20 (Tons)</td>
</tr>
<tr>
<td>Nagoya</td>
<td>20/30 20/30 (Tons)</td>
</tr>
<tr>
<td>Kure</td>
<td>20 20 (Tons)</td>
</tr>
<tr>
<td>Taiwan</td>
<td>19.4/19.9 19.4/19.9 (M.T.)</td>
</tr>
</tbody>
</table>

It would be wrong and unfair to isolate the primary problem to the factor of stevedoring. Other aspects such as the corrosive nature of the cargo or even the environment can have a great effect on structural reliability and performance. In this respect certain coal cargoes can have a high sulphur content and this in association with the “sweating” of the steelwork, due to the environmental conditions experienced, can lead to very concentrated corrosion of the hull internal...
steelwork. This phenomena, together with heavy sea conditions can lead to extremely rapid break down in the integrity of the structural components.

Other aspects, such as how the quantity of ore in each hold can be ascertained during loading are also fundamental consideration in terms of the hull girder loading. Cargo temperatures in the carriage of certain pelletised ores and also coal, while being less common is an aspect of load which cannot be ignored. In a paper to the Tasmanian Branch of the National Institute during 1988 Captain Davies, a marine surveyor, assumed the hypothesis that the loading and carriage of high temperature iron ore pellets excessively degrades ship structures. In this paper he commented that ores were being loaded at well above the recommended temperatures of 65 degrees centigrade, with temperatures of over 150 degrees centigrade being recorded. Ref. 1.

(ii) Age Structure of the Fleet

The age structure of the bulk carrier fleet is shown in Figure 4. From this figure it will be noted that the fleet is a reasonably balanced fleet in terms of size, up to about 100,000 t dwt, for ships built between the early seventies and mid eighties. During the early eighties there appears to be an upswing in newbuildings for ships above 125,000 t dwt.

By far the majority of the ships which form the bulk carrier fleet are the handy sized ships ranging in age up to over 30 years.

(iii) Statistics of Losses

Figures 5, 6 and 7 illustrate the loss of dry bulk carrying ships, where such losses can be attributed to structural failure, from the end of 1979 to date. i.e. ships which have had reported hull leakages or have simply gone missing. The ship types include single hull and double hull bulk carriers as well as ships with an ore carrier structural configuration. Over this time period the average rate per year is about 6 ships with the highest level being 13 ships during the year 1991.
Bulk Carriers World Fleet as at April 1992 (inc. OBOs, Ore Carriers and Ore/Oil Carriers)

Figure 4

Bulk Carrier Losses Where Structural Failure May Have Been a Factor (inc. OBOs, Ore Carriers and Ore/Oil Carriers) (1980 - March 1992)

Figure 5
Bulk Carrier Total Losses Where Structural Failure May Have Been a Factor (1990 - 91)

Figure 6

Bulk Carrier Total Losses Where Structural Failure May Have Been a Factor (1980 - 91) 15,000 T. DWT Upwards

Figure 7
Ships which have been lost or have known to have suffered significant damage during the period from the beginning of 1990 to the time of writing are shown in Figure 8. From this information it can be deduced that the average age of the 25 ships which were lost during 1990 - 1991 was about 19 years, with the majority being over 20 years of age. The average age being influenced by the loss of the 'Mineral Diamond' which was only 9 years old. From this information it will also be noted that most were carrying iron ore. In nearly all of the cases (take off), except those where the ships have simply 'gone missing', it is understood that the loss was preceded by water being taken in one or more hold spaces.

From the information available for the handy sized ships it is evident that the rate of sinkings increases with age. i.e. less than 1% for ships in the 5 to 9 age group ranging to 4% for the 20 to 24 year group. In the case of larger ships there are indications that this trend is still applicable with the 50,000 to 75,000 t dwt group being up to about 7.5% when the ships are in the 20 to 24 year age group. With regard to ships in the 100,000 to 125,000 t dwt the very much smaller sample is relatively consistent in performance at about 7%. It required to be appreciated when considering these magnitudes that as the sample group sizes vary to such a large degree that the actual percentages are not comparable in ship number terms. These percentages do, however, indicate a trend for the various deadweight ranges.

In view of the difficulty in establishing probable causes for ship losses, information available with regard to bulk carriers with significant damages within the same time frame have also been included in these statistics. The information available indicates that cracking of the main frames and their brackets is a consistent occurrence. In certain cases this cracking has led to a reduction in support for the side shell which in turn has resulted in cracking occurring in the side shell plating itself. In at least two prominent cases this phenomena actually led to the loss of the side shell plating over the affected hold lengths.

These statistics used also seem to indicate that there are two distinct problem areas. i.e. one with the older ships and the other on a smaller scale with middle aged tonnage.
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<tr>
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<th>Type</th>
<th>Cargo</th>
<th>Casualty Details</th>
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</thead>
<tbody>
<tr>
<td>Ship 1</td>
<td>15</td>
<td>Bulk</td>
<td>Grain</td>
<td>Missing</td>
</tr>
<tr>
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<td>17</td>
<td>Bulk</td>
<td>Coal</td>
<td>Side shell lost No 1 hold.</td>
</tr>
<tr>
<td>Ship 3</td>
<td>19</td>
<td>OBO</td>
<td>Iron Pellets</td>
<td>Heavy weather damage</td>
</tr>
<tr>
<td>Ship 4</td>
<td>9</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>No 8 side shell lost</td>
</tr>
<tr>
<td>Ship 5</td>
<td>24</td>
<td>Bulk</td>
<td>Phosphate</td>
<td>Damage in No 2 hold (flooded)</td>
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<td>20</td>
<td>Bulk</td>
<td>Ballast</td>
<td>Fracture No 1 hold</td>
</tr>
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<td>Ore</td>
<td>Iron Ore</td>
<td>Foundered</td>
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<tr>
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<td>Ore</td>
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<tr>
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<td>22</td>
<td>Bulk</td>
<td>Barytes</td>
<td>2 m fracture in No 6 hold</td>
</tr>
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<td>Iron Ore?</td>
<td>Hull damage. Holds flooded</td>
</tr>
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<td>Hull damage. Flooded</td>
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<td>Bulk</td>
<td>Iron Ore</td>
<td>Fractures in holds 2 &amp; 3</td>
</tr>
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<td>Ship 13</td>
<td>23</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>No 3 hold flooded</td>
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<td>Ship 14</td>
<td>18</td>
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<td>17</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Missing</td>
</tr>
<tr>
<td>Ship 17</td>
<td>24</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Presumed to have foundered</td>
</tr>
<tr>
<td>Ship 18</td>
<td>19</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Wasted side shell framing in No 3 hold</td>
</tr>
<tr>
<td>Ship 19</td>
<td>17</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Fractures in holds 2, 3 &amp; 6</td>
</tr>
<tr>
<td>Ship 20</td>
<td>21</td>
<td>Bulk</td>
<td>Bauxite</td>
<td>12 m fracture in No 5 hold</td>
</tr>
<tr>
<td>Ship 21</td>
<td>19</td>
<td>Bulk</td>
<td>Ballast</td>
<td>Bulkhead frames loosened</td>
</tr>
<tr>
<td>Ship 22</td>
<td>18</td>
<td>Bulk</td>
<td>Iron Ore?</td>
<td>Fractures in No 2 hold</td>
</tr>
<tr>
<td>Ship 23</td>
<td>17</td>
<td>Bulk</td>
<td>Potash</td>
<td>Damage to frames in No 1 hold</td>
</tr>
<tr>
<td>Ship 24</td>
<td>18</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>No 2 &amp; 4 holds flooded</td>
</tr>
<tr>
<td>Ship 25</td>
<td>24</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Fractures &amp; detached frames in two holds</td>
</tr>
<tr>
<td>Ship 26</td>
<td>19</td>
<td>Bulk</td>
<td>?</td>
<td>Fracture in No 5 hold. Flooded</td>
</tr>
<tr>
<td>Ship 27</td>
<td>24</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Fracture in No 1 hold</td>
</tr>
<tr>
<td>Ship 28</td>
<td>21</td>
<td>OBO</td>
<td>Iron Ore</td>
<td>Fractures in no 3 WB hold</td>
</tr>
<tr>
<td>Ship 29</td>
<td>14</td>
<td>Bulk</td>
<td>Ballast</td>
<td>Took water after striking object</td>
</tr>
<tr>
<td>Ship 30</td>
<td>24</td>
<td>Bulk</td>
<td>Pig Iron</td>
<td>frames detached from No 6 hold</td>
</tr>
<tr>
<td>Ship 31</td>
<td>17</td>
<td>Bulk</td>
<td>?</td>
<td>No 1 hold flooded</td>
</tr>
<tr>
<td>Ship 32</td>
<td>24</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Fracture in No 4 hold. Flooded</td>
</tr>
<tr>
<td>Ship 33</td>
<td>21</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Missing</td>
</tr>
<tr>
<td>Ship 34</td>
<td>9</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Fracture in No 1 hold</td>
</tr>
<tr>
<td>Ship 35</td>
<td>16</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Fracture in hull below waterline</td>
</tr>
<tr>
<td>Ship 36</td>
<td>16</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>No 3 hold flooded</td>
</tr>
<tr>
<td>Ship 37</td>
<td>15</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Grounded No 1 hold flooded</td>
</tr>
<tr>
<td>Ship 38</td>
<td>21</td>
<td>Bulk</td>
<td>Steel</td>
<td>Severe crack No 7 hold</td>
</tr>
<tr>
<td>Ship 39</td>
<td>21</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Ingress of water No 1 or 2 hold</td>
</tr>
<tr>
<td>Ship 40</td>
<td>16</td>
<td>Bulk</td>
<td>Iron Ore</td>
<td>Shell fracture frames detached No 3 hold</td>
</tr>
<tr>
<td>Ship 41</td>
<td>12</td>
<td>Bulk</td>
<td>?</td>
<td>Heavy weather frames cracked</td>
</tr>
<tr>
<td>Ship 42</td>
<td>14</td>
<td>Bulk</td>
<td>?</td>
<td>Disabled towed to safety</td>
</tr>
<tr>
<td>Ship 43</td>
<td>23</td>
<td>Bulk</td>
<td>?</td>
<td>No 5 hold frames fractured</td>
</tr>
<tr>
<td>Ship 44</td>
<td>24</td>
<td>Bulk</td>
<td>?</td>
<td>Hull fractures</td>
</tr>
<tr>
<td>Ship 45</td>
<td>18</td>
<td>Bulk</td>
<td>Oil</td>
<td></td>
</tr>
</tbody>
</table>
(iv) Focal Points for Structural Defects

In a sense the particular ship configuration and service dictate the location and extent of damages on ships. In the case of bulk carriers the cargo containment space is bounded by the port and starboard side shells, the ship's inner bottom and is normally subdivided along its length by corrugated transverse bulkheads which have supporting stools top and bottom. The presence of large hatchway openings over the cargo area also creates a hull with a reduced torsional resistance, as well as focal points for stress concentration at the corners of the hatchways. While seemingly not obvious the structural arrangements employed for transverse bulkheads can also create, under certain loading conditions, concentrations of load in the deck structure and in particular the cross deck strips between the hatchways. In addition to these aspects the handling of cargo can damage certain areas of the structure more than others by virtue of grab damage or even that created by bulldozers or hydraulic hammers. The cargoes themselves by virtue of their temperatures or their corrosive properties can also be fast acting and ruinous to the structure. Other aspects,

Such as structural discontinuities, can of course also be focal points for cracking.
A brief summary of types of defects and the locations where these can be found is given as follows:

i) Cracking at hatch corners.
ii) Plate panel buckling of cross deck strips and stiffening structure.
iii) Cracking of hatch coamings.
v) Cracking at the intersection of the inner bottom plating and the hopper plating.
vi) Grab and bulldozer damage to the main frames lower brackets.
vii) Grab damage to the inner bottom platings, hopper and lower stool platings.
viii) Cracking at main frame bracket toes.
ix) Both general and localised corrosion of main frames and brackets.
x) Cracking at fore and aft extremities of topside tank structures.
xii) Corrosion within topside tanks.
xii) General corrosion of transverse bulkheads.

While the above listed damages are typical of those found on bulk carriers they are not inevitable. Evidence would seem to indicate that even with sister ships significant differences in occurrence and extent do exist. This would seem to indicate that in addition to the importance of structural strength and detail design, that other factors, such as operational controls, come into play.

An aspect considered relevant with regard to loadings is the procedure and the number of loading passes made by the loaders on the individual holds of the ships. Again for commercial reasons it is in the ship operators' and port operators' interests the number of passes be kept to the minimum. In considering a group of very similar ships carrying very similar cargoes it becomes apparent that great variations in structural performance do occur. With the ships which incur minimum damage it would appear that the operators are particularly cautious with regard to loading ore cargoes and employ a large number of loading passes which will reduce the likelihood of overloading individual holds.

For the purpose of this paper it is not intended to discuss all of the items listed beforehand but to address only those aspects which are more likely to cause hold leakage and progressive flooding.

The remaining aspects have been, or are being, dealt with and will be reflected in rule reviews in the near future.
Grab and bulldozer damage to main frame lower brackets

As previously indicated it is normally expected that the lower region of the main frames at some time receive some level of damage during the unloading of the ship. This can involve damage ranging from localised deformation of the frame bracket face plates to large physical deformations of a number of frames.

In the case of single hull bulk carriers the ships side main frames are individual pieces of structure, which, if rendered ineffective, will place additional load on the adjacent main frame or frames. Progressive failure by the domino effect is therefore a reality.

Cracking of main frame bracket toes

This type of cracking is initially created by detail discontinuities in the bracket toe regions. The type of bracket configuration used will to a large extent dictate the location and extent of cracking. Where separate brackets are employed the cracking location is more normally at the bracket toe position on the frames whereas with integral brackets the crack location is at the toe location on the hopper and topside tank. See Figures 10 and 11 respectively. Turning to the latter case first i.e., the contiguous bracket design, the cracking has been found to be almost self limiting with a very small propagation rate after the initial occurrence. In the case where separate brackets are fitted experience has shown that the fracture, once it has occurred, propagates very quickly to the side shell.

These experience-based conclusions have been confirmed by experimental and theoretical studies, carried out by Japanese shipbuilders, to determine the fatigue characteristics of various configurations of frame bracket. Ref. 2.

Loadings on the main frames and their brackets are complex and are generated by hydrostatic load and the rotation of the hopper and topside tanks. Cyclic loadings are induced from these load sources by the passage of waves and the motion of the ship in a seaway. See Figure 12.
Frame/hopper deformation in Ore loading condition

Figure 12
Repair of Defects and Damage

Inspection of the ship by shipowners after cargo discharge on many occasions will reveal some level of damage. In many of the ports where unloading takes place there are no facilities for repair and therefore the owner can be faced with a decision as to whether to accept the damages as (i) being only a blemish, (ii) to carry out temporary repair and carry out permanent repairs later or (iii) to sail to a repair facility. It is emphasised that any significant damage should be advised to the classification society concerned. Commercial pressures will have inevitably influenced in the decisions taken in the past.

A fundamental question is; how can the internal structure of the holds be effectively examined in any case? The lower frame bracket areas can be accessed by means of ladders but how can the upper reaches of the cargo holds be accessed? To enable effective examination so as to assess corrosion or even cargo handling damage means to permit close up examination are fundamental, i.e. by the use of ‘cherry picker’ type equipment.

Both general and localised corrosion of main frames and brackets

The marine environment in association with the characteristics of certain cargoes can create a very severe situation in terms of corrosion. This has been very adequately demonstrated over recent years by the loss of ballast tank side shell structure on oil tankers due to differential temperatures between cargoes and the environment.

In the case of single hull bulk, or ‘ore bulk oil’ carriers the environment created within the hold spaces by a cargo, such as coal which is carried at temperatures of up to 38 degrees centigrade, can create, in association with the colder sea water outside, significant sweating at the interface of the side shell and topside tanks. In addition to this certain coal cargoes possess a high sulphur content which adds to the corrosive effect. By virtue of gravity the condensation is limited to the outboard portion of the main frame webs and the lower bracket connection to the hopper to which it gravitates.
It is not unusual therefore to find that bulk carrier main frames have suffered from highly localised corrosion on their webs adjacent to the side shell. In addition the bracket web connection to the hopper is similarly effected.

This corrosion, with some typical structure arrangements, would seem to be the trigger for fracturing which either propagates from the lower bracket toe outboard or up the web connection to the side shell (leaving the bracket intact).

**Corrosion of Transverse Bulkheads**

In the event that high sulphur bearing cargoes are being carried the (environmental conditions as previously mentioned) within the hold spaces also attacks the transverse bulkhead platings, if these are unprotected and this can create an increased rate of corrosion on these structures. As a principal failure mode for these members is the buckling of the corrugation flanger this can be very consequential, particularly in the event of hold flooding.

(v) **Development of damage**

In the case where integral brackets are employed experience has shown that, in the absence of corrosion, any fatigue cracking will be contained in very localised areas at bracket toes. It has also been shown that where localised corrosion has occurred in association with localised fatigue cracking that this cracking propagated to the side shell along the bracket connection. In the absence of significant mechanical damage to the main frames this cracking, by virtue of its location, will be difficult to detect. In addition due to the consistency of structural arrangements, loads and the environment it is probable that the other frames in the same hold will be in a similar condition. If this situation goes unnoticed it is only a matter of time before the side shell cracks and tears thus permitting sea water into the hold space.

An obvious question to address would be: why does this damage more often occur when the ships are carrying ore as the evidence suggests? The obvious answer to this is that when carrying ore, particularly in the alternate hold loading condition, both the local components, such as the frames, and the hull girder are more highly stressed. In addition, because of the low fill rates of the ore cargoes the side frame deflection amplitudes and
panting are not restricted. Also the ship’s very stiff rolling motions in the ore conditions can only exacerbate the loading situation.

With regard to the ships transverse bulkheads any hold overloading would create additional transverse forces and stresses as well as additional magnitudes of shear stresses, in the platings.

In the event that sea water entered the hold space the effect of sloshing, perhaps exacerbated by the excessively reduced scantlings of the platings could initiate failure.

An obvious question is "why do the ship sink"? The answer is not so obvious as any relevant evidence sinks with them. A number of hypothesis can of course be developed. In terms of probability these are two predominant possibilities which come to mind. The first of these is the flooding of a forward hold which results in the collapse of a bulkhead (for the reasons given beforehand) which then results in the ships bow becoming submerged and progressive flooding taking place. Another possibility is the flooding of centre holds and the ships ultimate strength being exceeded, resulting in the hull breaking in two. Both of these potential scenarios would be supported by the evidence available in terms of corrosion and the absence of any form of Mayday call from the ships concerned.

(vi) Conclusions

• If this portrayal of the situation is correct it would seem that there is a need to introduce a greater degree of structural reserve so as to improve the robustness of the hull thus making an allowance for a degree of human error. This is particularly true with regard to the side framing members.

• There is a need for an awareness in the ship operating community with regard to the possible consequence of damage to main frames, whether this is caused by cracking and corrosion or by the act of unloading the ships.

• There is a need to prevent corrosion occurring in these critical locations.

• Bearing in mind the age statistics of the ships concerned it would seem logical to require an increase in survey requirements, for hold areas.
• It would also seem logical to look to the future and ensure that new designs being constructed of higher tensile steels reflect the experience gained.

• While more a long term objective it would seem that positive means should be developed to gauge more accurately the ore filling levels and also to announce the ingress of water into hold spaces.

• It is considered that the lower frame brackets require to be increased in thickness because of their working environment. In addition it would also seem logical to consider the use of additional structure to provide an alternative load flowpath in the event of local failure.

Actions implemented with regard to Ship Structure

• Scantlings of main frame brackets increased.

• Scantlings of transverse bulkheads increased.

• IACS agreement to coating side shell and transverse bulkheads.

• Survey programme made more rigorous.

Work Still Ongoing

• Development of means to evaluate weight of cargo in holds during the loading process.

• Full scale measurements of stress magnitudes in side framing structure.

• Assessment of ships reserve ultimate strength in the flooded condition.

In conclusion I consider that the challenge for the classification societies is relatively clear but the effort of their actions will only be significant if an awareness of the consequences of damage is reflected in action by Industry.

There is still a degree of concern regarding the rapidity of the ship sinkings and the fact that the crew are apparently unaware of any structural failure or flooding.
In typhoon conditions the ship would behave differently and visibility may not be good and therefore experience and watchfulness may not be adequate. In this respect it is considered that a system of stress monitors on the ships deck could provide a level of warning that changes in the baseline stress were occurring. The adequacy of the warning would depend greatly on how quickly the ship was flooding and how many holds were effected.

Ref. 1  Arctic Carrier, 1985 - A contributory cause of loss? - Captain Davies, 1988

Ref. 2  Study on the fatigue strength of local parts ships structures 2nd report - Strength of side frame ends of Bulk Carriers - I H I, 1978
Structural safety and fatigue of ships

J.J.W. Nibbering

Abstract:
The high stress level in ships - largely due to the use of higher strength steels - has made fatigue a major problem for shipowners and classification societies. It will be discussed that fatigue-cracks are not merely a nuisance (leakage and repairs), but that they constitute a and probably the main danger for the safety of ships against (brittle) fracture. It is doubtful whether sophisticated fatigue and reliability calculations are of much use in this respect. Rather they may give a false feeling of safety. Better design of details and especially improved workmanship (welding), are more valuable. Examples will be given.

Introduction:
Reliability theories and procedures have developed spectacularly in recent years. Applications in structural design are coming in use. But the reliability of the outcome of these activities for individual cases is not (yet) large. The problem is that the experts in reliability are seldom sufficiently expert in the various specialities involved in structural design. Perhaps the aspect of "loads" is the best treated link of the structural design chain, thanks to the fact that reliability-theorists and load-experts are on good statistical terms. But often several of other links, like fatigue, corrosion, fatigue, weld-parameters and their consequences (defects, heat-affected zones, residual stresses and deformations) inspection methods and detection possibilities (N.D.T.) acceptance testing, fabrication of structural details (tolerances, distortions, misfits, poor painting,) may be more or less outside their scope.

But let us be optimistic. For off-shore structures balanced integration of all aspects of structural design is so important - and the money so available - that sooner or later shipbuilders may simply buy commercially available programs for making estimates of structural capability. But even then they should be aware that the reliability of the outcome is determined by the accuracy and soundness of the input (f.i. shipyard parameters in the widest sense.)
Fatigue damage in ships.

It should be realised that fracture problems of ships differ from those of off-shore structures in many respects. Ships have an all-covering skin as a most important structural item; they are severely longitudinally loaded, can easily be inspected and repaired and can escape from or adapt to bad weather conditions.

Ships which are "simple" from the structural point of view like tankers, hardly need thorough fatigue-calculations because the feedback from existing ships is sufficient (and probably more reliable). Of course also these suffer from cracking but often this is partly due to the urge from shipyards and shipowners to build ships at low cost per ton deadweight.

This had led to the wide use of the higher strength steel Fe 510.

In general this only helps in cases of ships in which still water loads differ largely from one trip to another, overall or more locally (loaded ballast).

The normal loss of fatigue-strength due to the higher stress level when using Fe 510 should be compensated for by better design and fabrication of structural details. Unfortunately this may reduce greatly the benefits of economising on material (and welding?).

Protection against corrosion is of utmost importance and certainly in order to avoid corrosion fatigue. Expensive methods to protect ballast tanks do often not succeed in avoiding cracking of paints in corners and at structural discontinuities.

Precisely where the protection is badly needed, it does not work.

This is another argument for smoothing welds at these spots by grinding, T.I.G.-welding and such in order to keep the new paint intact in service.

How can anybody believe that even the best paint will do its job in flame-cut edges of holes in stiffeners through which dirty, perhaps sandy water may pass at high velocity.

In a paper by Ferguson and Osborne [1] and Lloyd's Reg. [2] on cracking due to grabs, bull-dozers, ore etc. the accompanying loss of paint (very soon) corrosion, (wet ore, condensation, and coal) and bulging of brackets make the structures very vulnerable to corrosion-fatigue.

Double hulls may pay!

Both papers are very informative and practical and are of greater use for shipbuilders and owners than the beforementioned papers on reliability. This may not sound sympathetic to those working in that field, but that is not the intention. It is more a plea for doing first things first. To that belongs insight in and knowledge of basic items of fatigue and fracture. The best start is buying the Fatigue Handbook [3]. For those who have already come thus far, papers in which applications of reliability methods for ships are given can be very instructive.
They show the overall complexity of the problems and often give data of which the value can be judged by own research and common sense. Examples are papers appeared in Marine Structures [4] by Akita (informative), Guedes Soares and Moan (most practical), Pittaluga et al (shows many uncertainties in design), Juncher Jensen (loads). Also the U.S.Ship Structure Committee has been active in the field for years. See for instance the proceedings of the 1984 Symposium [5].

In the present paper it is only possible to mention a few primary aspects which are poorly or even wrongly treated in several of the befo'rementioned papers. It has to do with overall strength and critical crack lengths. Connected to it are practical hints which may greatly simplify fatigue analyses for designers coping with time limitations.

Cracking impairing longitudinal strength.

Perhaps the weakest item in papers on reliability in connection to fatigue is critical crack length. This may be connected to the fact that often fatigue experts and brittle fracture specialists seem to live in separate worlds.

The origin is probably that brittle fracture is mainly a material problem and fatigue more a "mechanics" one. In hardly any of the befo'rementioned papers temperature appears as one of the parameters in the whole analysis. Yet it is the most crucial one for welded structures. One might say that when a crack has become unstable, it is of little interest to know whether it was a brittle or a shear one. But the difference is large and has serious consequences for the safety of a ship. A brittle fracture, once started, very soon propagates at a speed of 1 to 2 Km/sec. This means ultra high-speed loading of the material ahead of the crack. Because steel is very sensitive to such loading, its fracture toughness drops to values of 1/100 to 1/1000 of that for low speed loading. Due to that it can hardly stop.

In case of shear fracturing the drop in fracture toughness is an order of magnitude smaller and often negligible. Due to that the speed of propagation is small. Both factors make that when a shear fracture starts in a ship f.i. due to a combination of a high wave load and a severe slam. (see fig. 2) the fracture cannot come far because the part of the load due to the slam drops quickly. After 1/4-1/2 sec. the dangerous situation is over.

The arrested shear fracture may have a length of centimeters but will not easily start again, unless a similar extreme load occurs. Even then, the phenomenon of a jumping and halting shear crack may be repeated several times.
It would be wise to test the shearing strength of steel in presence of fatigue cracks as a routine-check, because this property can differ largely between steels and also depends on thickness.

Shear fractures and fatigue cracks can be arrested—or at least largely retarded—by several simple measures like hole drilling, hammering around the tip, and forcing a wedge in the crack. It is something ship officers should be familiar with.

What are the main types of brittle fractures which start at fatigue cracks.

The first one is a pop-in at a local brittle zone (L.B.Z.) in a weld or heat-affected zone.

In fact it is mostly a rather low stress fracture. Many people think that pop-ins hardly occur in ships because they are seldom found. But this does not mean that they do not exist. Mostly they start at small fatigue cracks in the welded region and are arrested immediately outside that region. Crucial is that that region is generally so small that the energy set free at crack extension (proportional to the root of cracklength) is still little when the crack-tip arrives in the sound parent material. Fig 1 illustrates the situation.

It may be surprising that small fatigue-cracks (mm's) can be, and often are more dangerous than larger ones (cm's). The unsympathetic aspect of a fatigue-crack in welded structures is that it patiently "seeks" the worst place in its weld region.

When at that time the weather is stormy and the temperature is low a brittle fracture may start. The risk that it does not only "pop-in" but propagates far (and too far) is significant.

High Charpy-values do not guarantee arresting. High C.O.D-values say nothing about crack-arrest properties. A C.O.D.-test is a static one and for arresting is dynamic fracture toughness relevant.

One of the first investigations in the Ship Structures Laboratory concerned a brittle fracture started at a fatigue crack in a bilge keel.[6] The crack was only 3 mm deep. There is no need to show it here because a few years ago numerous pop-ins were found at draining holes in bottom stiffeners. It is not so much a miracle but certainly very fortunate that not any pop-in lead to a large brittle fracture (fig. 3). But it is obvious that such local brittle cracks might once start again at greater lengths when they have grown due to cyclic loading.

Normally ship's steel is good enough to tolerate such cracks and that is the reason that few ships fracture in two. But these cracks will inevitably develop in large (complete) fractures when the longitudinal stresses exceed yield point. It is curious that still many people do not realize why this is so dangerous. Imagine a plate with a central through-crack in it.

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Below yield point (in the net-section) the nominal deformation is in the order of 0.15%.
At yielding it grows to about 1%.
The consequence is that also the crack-tip material has to deform suddenly 7-fold. It means that the crack-tip opening displacement (C.T.O.D.) may grow from for instance 0.2mm to about 1.5mm. and that is too much.

When temperature is close to 00 a brittle fracture is highly probable. It will not easily be arrested in Dor E-quality plates because the energy set free per unit crack propagation is high: high stress, long crack.
It will be clear that in this respect a high-yield point of the steel is of great advantage. (see next section)

Returning now to the pop-ins at local brittle zones it is obvious that a large number of C.O.D. tests are required for finding the worst spot in a weld of H.A.Z.

Far more realistic, reliable! (and cheap) is fatigueloading at low temperature [7]. The growing of the crack acts as "screening" of the zone.

The joint probability of extremely high wave loads and low temperatures.

The situation in the field of loading is similar to that in the field of testing. Above it has been emphasized that fatigue and brittle fracture experiments should not be separated but combined. When we look to loading there is an enormous amount of literature on wave-induced loads and their extremes, and also on temperatures of air and water, but nothing about the probability of occurrence of extreme loads at low temperatures.

We have repeatedly brought this aspect to the notice of relevant ISSC-committees, but the situation is still bad. Therefore it was tried to find something in the (scarce!) literature on ships' fractures. Among these was "A study of extreme waves and their effects on ship structure" by W.H.Buckley [8]. As the title says, the paper was focussed on extreme sea-states. Consequently nowhere in the text relations with temperature appear. But fortunately in the appendix a table of data is given with particulars of ships, the weather conditions and the damages. The following information could be drawn.

38 Heavy-weather cases; in 31(!) cases the temperature was between +10°C and +25°C. The rest was as follows:

<table>
<thead>
<tr>
<th>Ship no.</th>
<th>Sea temp.</th>
<th>Air temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>+3</td>
<td>+1</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>+7</td>
</tr>
<tr>
<td>15</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>19</td>
<td>+4</td>
<td>+2</td>
</tr>
<tr>
<td>31</td>
<td>0</td>
<td>-3</td>
</tr>
<tr>
<td>33</td>
<td>+3</td>
<td>+7</td>
</tr>
<tr>
<td>38</td>
<td>+7</td>
<td>+2</td>
</tr>
</tbody>
</table>

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As a matter of fact the sea temperature is the most characteristic one. There were two cases where the damage consisted of cracking. Ship 31 was the SL7 container ship Sealand Market. There was a "hairline crack in the main deck at the forward end of no. 2 hatch with a length of 14 inches". A crack of that length may be a fatigue crack, but it is equally possible that it was an arrested brittle fracture, started at a small fatigue crack.

Ship 15 was a 16000 ts dw dry-cargo ship, built in 1969: "There was a sharp loud crack heard throughout the vessel. A fracture in the main deck at hatch no. 4 was sighted from the bridge deck with a length of 16 feet".

From the foregoing it may be deduced that brittle fracture (only?) occur due to combinations of extreme loads and low temperatures. Perhaps the most convincing fact is that the other 36 ships did not get brittle fractures. The probability of occurrence might be taken as the product of the probabilities of for instance loads higher than the one year extreme and temperatures lower than the one year minimum. In that case both phenomena are thought to be independent variables. When some correlation exists it may be as well positive as negative. What we ideally should dispose of are joint probability functions for loads and temperatures. For ships and floating offshore structures this could be restricted to sea temperatures (winter and spring). For jack-ups and jackets also air temperatures are of concern, and eventually the temperature of that part of the structure which is above sea level. The latter may be different from air temperature in case of high waves. A dramatic disaster supports the need of data. In January 1977 a ship fractured completely near Cape Ann, Mass. The water there is cold at that time. The wave was 90 m long and 14 m high, which means an extreme steepness of 1:7. The ship had a length of 85 m. So the wave height was nearly three times as large as that of a conventional standard wave (L/20). Again a combination of a high load and a low temperature occurred.

In [9] the case of the Sealand Market has been further analysed. It came out that at hatch corners fatigue cracks must develop after two or three years service. Furthermore it was shown that it is highly probable that the ship once survived in extreme stormy conditions (fig. 2), thanks to the use of Fe 510 in the deck-box girders. When the ship had been made totally of Fe 410, as was the original wish of the shipowner, a plastic hinge midships would have developed. This would have led to nominal strains in the deck of about 1%, which normally cannot be tolerated in the presence of fatigue cracks at the temperature concerned.
How well fatigue loading at low temperature simulates service behaviour is illustrated in [10]. In the Delft Ship Structures Laboratory high stress fatigue loading was applied at -100°C with a full-scale cross connection of tubes of 368x20 mm. The yield point of the steel was 850 N/mm². A complete fracture occurred when fatigue cracks at the fusion line had a depth of only 2 mm. The realism of this alarming result was demonstrated in January 1985 when the 10 years old Beryl SPM1 broke in two. It was evident that fatigue cracks were present in the lattice structure made of tubes [11].

"On the safe side" design procedures.

A Fitness for purpose. Fatigue and fracture analyses for maritime structures largely tend to be on the safe side. For instance for S-N-curves (Wöhler) for welded connections, lower regions of scatterbands are used. Welding stress are always taken tensile and equal to yield point. Crack closure is neglected. The beneficial influence of tensile overloads, both in connection to welding residual stresses as from the pure fatigue point of view, is not taken into account. Also it is seldom realised that in brittle fracture control the existing (Charpy) specifications have emerged from practical experience and consequently are not "averages" but "safe" values. On the other hand there are also approaches which are too optimistic. Post-weld heat treatments are not always as beneficial as is hoped. It may give rise to cracking, destroy compressive residual stresses at critical points or - in case of heating parts of existing structures - bring forward new stresses and deformations. Furthermore it can (and will) be shown that the generally held idea that high-stress fatigue strength is not impaired by corrosive environment, is not justified. The influence of neglection of changes of mean stress has been discussed earlier [12]. In the following a case will be discussed, in which every possible aspect of fracture analysis was on the safe side. The whole story is no fantasy, but reflects an actual stage in the design of an existing offshore structure!

The problem started when it was observed that in a multi-run X-weld in a thick plate the specified C.O.D.-values could not be met in the as-welded condition. The critical crack lengths calculated from the measured C.O.D.-values were in the order of magnitude of only a few mm's. The crack lengths calculated on the basis of the expected loads in 20 years, hot-spot stresses, N.D.T.-defect lengths, Miner's rule and B.S.153 S-N-curves, were about ten times as large as the critical ones. The situation seemed to be hopeless. The decision was taken to replace several meters of welds, and heat-treat others on the spot.

In the author's opinion, the outcome would have been different, when not every part of the analysis had been unduly conservative.
The main point was a complete neglection (or misunder-
standing) of the role of the residual welding stresses. 
When a multi-run X-weld is made by alternatively laying 
beads on both sides of the plate, the residual stresses are 
tensile at the surfaces and compressive at the root of the 
X. Important defects are mostly only present in the root 
(slag inclusions, lack of penetration, root cracks), where 
the state of stress is highly triaxial (plane strain). 
Consequently crack growth, if any, can start at the root. 
Now the fatigue calculations were made according to a 
standard procedure. In it it was stated (as usual!) that 
tensile residual welding stresses are present around defects 
and should be taken into account. Yet in the case considered 
(root) the welding stresses were compressive! (Most 
unrealistic was that even for structural parts which were 
loaded in compression, fatigue calculations had to be made, 
because of the presumed presence of tensile welding stresses 
in the X-roots!). 
A calculation procedure in which residual stresses were 
simply neglected resulted in zero crack growth! 
But this is not yet the whole story. The C.O.D.-testing it 
self for estimating critical crack lengths had been carried 
out in a way which also suppresses the beneficialeffect of 
compressive welding stresses in the centre, where toughness 
is worst. It is well-known that in order to be able to 
supply a C.O.D.-specimen with a straight fatigue-crack, 
precompression in the thickness direction of the notched 
zone is applied. This has two effects: elimination of the 
welding stresses, and strain hardening of the material. 
This may reduce substantially the C.O.D. of the weld 
metal. Consequently the corresponding critical crack lengths 
will certainly be smaller than what is justified.

B Residual welding stresses.

Welding stresses have a clear influence on the 
fatigue-strength for constant amplitude/constant mean 
stress loading. 
The smaller the cyclic stresses the larger the influence. 
However, in actual structures welding stresses disappear 
quickly when incidental high loads occur. The first storm 
will do the job. It is often thought that this is only true 
in case the nominal stresses approach yield point. But 
figure 4 demonstrates that for a mild discontinuity being a 
circular hole, a nominal stress of only one third of yield 
point eliminates the welding stresses completely. 
In ships much higher stress (strain) concentrations are 
present. Precisely at these points where the danger of 
cracking is greatest, the residual stresses are soon 
relieved.

In the absence of residual stresses the phenomena of crack 
closure and the Elber-effect can occur. This may cause 
increases in fatigue-life in the order of magnitude of a 
factor 5.
For when a crack of a few mm's has formed, the compressive part of a load cycle (in alternating loading) becomes insignificant. Also in repeated axial loading on a centrally notched 500 mm wide plate of 19 mm thickness, crack closure was manifest. The effective load was only about 75% of the real load (Elber effect).

0 Ultra low cycle—corrosion fatigue.

This section will start with a quotation from a paper of Det Norske Veritas /18/ on corrosion fatigue: "In the low cycle fatigue range, normally defined to be less than 100,000 cycles, the deterioration promoted by seawater is less". This is a generally held opinion. The arguments are in the sense that the crack growth is faster than the penetration rate of the corrosive environment. The cyclic frequency of the high loads is apparently taken equal to that of the lower loads (0.1 Hz for ships). Fig. 2 allows another look into the situation. The "built up" stress—change of 370 N/mm² occurs about once a year. Changes of some 300 N/mm² will be more frequent, but the frequency remains (very) low. Severe slamming may occur two to three times per hour. Still waterloads are also very low frequent.

In order to get an idea about the corrosion fatigue damage caused by ultra—low frequent extreme stress cycles, experiments were carried out [14]. One typical result for 0.0003 Hz is that after about 1500 cycles the crack in the seawater specimen was nearly 10 mm in length. In the accompanying air-specimen it was only 0.5mm! In conclusion it may be said that extremes occurring at large intervals contribute effectively to crack growth in seawater. A few thousand changes of hot—spot stress between 0 and σf at places where weld defects are present may lead to some 10mm crack extension.

Final observations.

In view of the scepticism expressed about the actual, practical value of reliability calculations in connection to safety for fracture, the designer may take benefit from the following observations. Shipfatigue is essentially corrosion fatigue. For that, sequence effects and load peaks have far less influence on lifetime than in case of cyclic loading in air. Also relief of residual stresses is less important. For 3-dimensional structural details crack growth calculations have many pitfalls. Of course finite element calculations are indispensable. For those details where full scale experimental results are available the application of Miner's rule is obvious. The Miner's sum should be taken 0.3 in stead of 1, when the experiments had been carried out in air. Make preferably use of experiments for repeated loading (R=0) or R= −1/2.

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It is on the safe side and allows for residual stresses. Steel strength and quality do not matter: results for Fe 410 differ little from those for Fe 510. (But for critical crack length quality has an enormous influence). The Delft Ship Structures Laboratory has largely contributed to the literature on fatigue of ship structural components. These may be used for Miner calculations [12]. Kathodic protection improves fatigue properties greatly [13]. It may be cheaper than painting! Fig. 5 summarises a lot of corrosion fatigue results. The new item is results for longer lives. In [13] the same figures can be compared for equal thicknesses. Thickness has an important adverse effect on fatigue-strength.

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Figure 1: Relative importance of crack length and crack tip position in a welded region.

Figure 2: Extreme bending stresses of the land-McLean recorded during a winterstorm.

Stresses and deformations at discontinuities with stress/strain concentration = 3

Figure 3: Pop-in from tiny fatigue crack.

Figure 4: The disappearance of welding stresses by high loads.
Figure 5. Fatigue-data for air (top), seawater and Cathodic protection (bottom).
Welding induced imperfections and collapse of ship plating in compression
M. Kmiecik

Abstract
Analysis of the load-carrying capacity of plates under uniaxial compression was carried out in elastic-plastic range with due allowance for large plate deflections. The calculations were performed with finite element method (FEM) computer code PANFEM, developed at the Ship and Offshore Structures Mechanics Department, Technical University Szczecin. Plates were analyzed having dimensions which mostly appear in ship structures. Results of measurement of post-welding deflections of plates are presented and their influence on the load-carrying capacity of ship shell plating is discussed. Combined effects of post-welding deflections and stresses are also examined.

Introduction
Plates constitute basic structural elements of all ship structures. Uniaxial compression dominates in many parts of these structures therefore the performance of plates under this loading condition is of considerable importance for practice. This particularly is the case when the load-carrying capacity of the ship hull girder is to be determined. The phenomenon of shrinkage which accompanies the welding process is the reason why structures which have been fabricated by means of welding are always to a greater or lesser extend deformed and contain balanced internal stresses. At present, welding is the dominant process in the joining of steel elements and thus is the main source of fabrication distortion of the stiffened plates of the ship shell-plating and the residual stresses occurring there. Results of measurements of these imperfections are presented below and their effect on the ultimate strength (collapse load) of plates under uniaxial compression is examined.
Characteristics of ship's hull plating
Ship's plates dimensions proportions differ from those encountered in other metal structures. Figures 1 and 2 contain histograms of plate aspect ratio \((a/b)\) and of plate slenderness \((b/t)\) of ship's hull plating. In the figures values of means and variances of these quantities are also given together with the number of the plates which dimensions were examined. The examined plates were of general cargo ships, bulk carriers, OBO carriers, chemical carriers, refrigerated vessels, tankers as well as passenger/car ferries. The deadweight of the ships investigated was within 1,900 and 116,280 tons.

Plates boundary conditions
Plate ultimate strength is associated with large deflection what in turn results in considerable displacements of its middle plane. Plates with simple and clamped supports were analyzed and with boundary conditions for the edges of their middle planes that, like simple and clamped supports, also constitute two extremes, namely:

- the edges unrestrained; unloaded edges of the middle planes of plates unrestrained (free to pull in, \(v = 0\), \(\delta v/\delta x \neq 0\), Fig.6) while loaded edges remain parallel both before and after plate deflection (\(\delta u/\delta y = 0\), Fig.6),
- the edges restrained; the plate deflection is not accompanied by the displacements of the unloaded edges of its middle plane while the loaded edges remain parallel both before and after the deflection (\(\delta u/\delta y = 0\), \(v = 0\), Fig.6).

![Histogram of plate aspect ratio, a/b](image1)

![Histogram of plate slenderness, b/t](image2)
FEM computer code PANFEM

The numerical study was performed with the computer program PANFEM, developed by the Ship and Offshore Structures Mechanics Department, Technical University Szczecin. This is nonlinear finite element code for flat plates and flat stiffened panels with imperfections (initial deflections and stresses) under lateral and/or in plane loads. Large displacement effects are handled using total Lagrangian formulation. Isotropic hardening of material is assumed and Huber-von Mises yield criterion together with associated Prandtl-Reuss flow rule are applied. The Newton-Raphson and the Modified Newton-Raphson methods are utilized combined with the Powell and Simons (1981) or the Crisfield arc length procedure (1981) to handle both pre- and post collapse behaviour of plates and stiffened plates. PANFEM was calibrated with well documented experimental recordings published in the world literature. Very good agreement was obtained between PANFEM and experimental results (Kmiecik 1992).

Ship plating imperfections

Post welding stresses and distortions are highly varied. Structures with the same geometrical characteristics exhibit significant differences in the magnitude and geometry of their distortions and in the magnitude and distributions of stresses. These differences are the result of deviations in the welding parameters and depend on many uncontrolled factors in the production process as well as on the conditions accompanying the welding process, such as the initial distortion of plates and stiffening sections, the boundary conditions and the state of loading of the structure during welding, etc. As a result of this, welding stresses and distortions are treated as random variables whose magnitude can only be estimated on the basis of the appropriate statistical data.

Fig. 3 contains examples of post-welding bending distortions of three ship plates of varying aspect ratios, \(a/b\) (Kmiecik et al. 1990). The distortions were approximated by means of a double trigonometric series of the form:

\[
\frac{v_o}{t} = \sum_{i=1}^{n} \sum_{j=1}^{n} v_{(i,j)} \frac{i\pi x}{a} \sin \frac{j\pi y}{b}
\]

In the figure the values of the coefficients of the series are also given. The coefficients of the series were defined on the
Fig. 3. Examples of measured post-welding distortions of plates.
basis of the recorded deviations from the base plane of twenty or twenty five point on each of the five measurement paths of a plate. The measurement paths are shown in Fig. 3. Report by Kmiecik et al (1990) contains a summary of results of almost fifteen years measurements carried out mainly in Polish shipyards in the process of construction of ships. In total about 2000 plates were examined. Results of statistical and regression analysis of the measurements are also given in the reference together with a short description of the measurement technic applied. The measurements confirm the random nature of ship shell plating bending distortions and their complicated geometric shapes.

In Fig. 4a an example of histogram of some of the recordings is given. The figure shows that the plate deviation from flatness is not normally distributed. The Weibull’s distribution provides the best fit to the results of the measurements. No correlation between relative maximum plate deflection, \( \omega_{\text{max}} / t \), and the plate aspect ratio, \( a/b \), could be established while practically linear relationship exists between \( \omega_{\text{max}} / t \) and the plate slenderness, \( b/t \) (Fig. 4c). Also linear relationship holds between the buckling mode component \( \omega_{o}/t \) and the plate slenderness, \( b/t \), and the plate aspect ratio, \( a/b \), (Figs. 4e,f). Comparison of Figs. 4c i 4d shows that \( \omega_{o(11)}/t \) component dominates in plate initial deflections which constitutes the buckling mode component for plates with aspect ratio of 1 - 1.41 (Table b in Fig. 4). Figs 4e and 4f also indicate that magnitudes of buckling mode components of initial deflections increase with plate slenderness, \( b/t \), but decrease with plate aspect ratio, \( a/b \). As can be seen in the figures initial deflections increase with plate slenderness and on average for plates with \( b/t \) between 30 and 100 one can reckon with \( \omega_{\text{max}} / t \) between 0.05 and 0.50.

A typical distribution of post-welding stresses in a plate to which stiffeners have been welded is shown in Fig. 5. To simplify the analysis straight lines were substituted for this distribution in FEM calculations.

Post-welding stresses as internal stresses are balanced, and in the tensile region their magnitude is equal to the yield stress of the material (Fig. 5):

\[
2\sigma_y \eta t = (b - 2\eta t)\sigma_r
\]

Thus the compressive stresses which have an effect on strength
Fig. 4. Statistical data and regression analysis of measured post-welding plate deflections

- Statistical data and regression analysis of measured post-welding plate deflections

- Pie chart showing Weibull distribution

- Table showing a/b vs Wo/t:
<table>
<thead>
<tr>
<th>a/b</th>
<th>Wo(11)/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1.41</td>
<td>0.1</td>
</tr>
<tr>
<td>1.41-2.45</td>
<td>0.2</td>
</tr>
<tr>
<td>2.45-3.46</td>
<td>0.3</td>
</tr>
</tbody>
</table>

- Graphs showing Wo_max/t vs b/t

- Graphs showing Wo(11)/t vs b/t

- Graphs showing Wo/b vs b/t

- Graphs showing Wo/t vs a/b

- Equation for stress:
  \[ \sigma = \frac{\sigma_y}{b/t - \frac{1}{2\eta}} \]

- Equation for strain:
  \[ \eta = \frac{1}{t(t_w + 2t)} \left( \frac{1}{F} + \frac{e^2 - \sigma_y}{J \cdot \mu Q_t} \right) \]

- Notes:
  - \( F \): Plate cross section area
  - \( J \): Plate cross section moment of inertia
  - \( \mu = -3.13 \cdot 10^{-6} \text{cm}^2/\text{cal} \)
  - \( q_i = 7250t_i \approx 2\text{cal/cm} \)
of plate during compression:

\[ \frac{\sigma_r}{\sigma_y} = \frac{1}{\frac{b}{t^2} - 1} \] (2)

In Fig. 5 the values of \( \sigma_r \) in relation to the slenderness ratio \( b/t \) of the plates which have been measured and calculated by various authors are also given (Carlsen 1976, Kmiecik 1986). As might have been expected, in practice one has to deal with a considerable variation in the magnitude of \( \sigma_r \) and thus also of the values of \( \eta \) for the same slenderness \( b/t \). As indicated by Guedes Soares (1988) in ship structures the mean of \( \bar{\eta} = 5.25 \) and the coefficient of variation of \( \eta \), \( V_\eta = 0.07 \). In accordance with Fig. 1 the average slenderness of ship plating \( b/t \approx 50 \) what together with the above numbers (after their substitution into (2)) results in average \( \sigma_r/\sigma_y \approx 0.25 \).

Effect of imperfections and boundary conditions

Figure 6 contain calculation results of the load-carrying capacity (relation: axial compressive stress - axial compressive strain) of simply supported and clamped square plates with two different and extreme - in terms of displacements - boundary conditions of the edges of their middle planes: the edges unrestrained (completely free to pull in) and restrained (no displacement at all in the middle planes). Initial deflection of the plates is in the form of regular half-wave:

\[ \frac{w_0}{t} = \frac{w_{0(1)}}{t} \sin \frac{\pi x}{a} \sin \frac{\pi x}{b} \] (3)

Calculations were carried out for initial deflections constituting 50 and only 0.5 per cent of plate thickness. The collapse loads obtained for the latter magnitude of the initial deflections, because of their very small values, are treated as the capabilities of perfectly flat plates.

In Fig. 6 critical loads are also given but only for plates with slenderness \( b/t = 100 \). Plates of this slenderness buckle in elastic range and in this range only exact expression for critical loads can be found in world literature.

As can be seen in Fig. 6 restraining the plate middle plane against displacement increases its load-carrying capacity considerably. This positive effect depends on the plate slenderness \( b/t \), and on the plate support (simple, clamped). Most affected are simply supported plates and plates with high
a) Simply supported

b) Clamped

Axial strain = \( u / a \)

Yield strain = \( \sigma_y / E \)

\( E = 206 \, \text{kN/mm}^2 \)

\( \sigma_y = 248 \, \text{N/mm}^2 \)

\( \gamma = 0.3 \)

Fig. 6. Square plates under uniaxial compression
slenderness. Simply supported plates are also much more sensitive to initial deflection than the clamped once. The initial deflection decreases plate ultimate strength; his effect is stronger for larger initial deflection and larger plate slenderness.

Fig 7 demonstrates the dependence of the load-carrying capacity on plate aspect ratio \( a/b \) and initial deflection \( w_{o(11)}/t \). Increase of initial deflection in the form of a regular half-wave decreases ultimate strength of square plates considerably (Plate 2 in Fig.7) while the strength of rectangular once increases (Plate 3 in Fig.7). This is due to well known shell effect as deflection in the form of half-wave is not sympathetic with buckling mode deflections of rectangular plates. Fig. 7 also indicates that the maximum deviation from plate flatness \( w_{o\text{max}}/t \) is not a rational measure for the detrimental effect of initial deflection on plate ultimate strength. Rectangular plate 3, 4, 5 and 6 in Fig. 7 have in fact the same \( w_{o\text{max}}/t \) (≈ 0.5) but their ultimate strength is distinctly different. It is not the maximum deviation from plate flatness \( w_{o\text{max}}/t \) but the geometric shape of the imperfection on which the ultimate strength of the plates depend and which also decisively effects the behaviour of the plates both before and after their collapse.

Fig 8 shows the effect of initial stresses on ultimate strength of plates. Practically no effect of the residual stresses on the ultimate strength of plates is observed at axial strain exceeding 1.5 yield strain. This result can be explained by the analysis of the behaviour of the plate shown in Fig.9 on the assumption that it will not buckle. Compression or tension of a plate without residual stresses will not change the elastic-plastic nature of the plate material. The existence of the residual tensile stresses at the plate edges equal to the yield stress decreases the plate stiffness under tension as the width of the plate is reduced to \((b - 2\eta t)\) already on onset of the tensile load. The ultimate strength of the plate is, however, not affected and is equal to the yield stress of the material. In case of compression, the existence of the residual compressive stresses \( \sigma_r \) accelerates the yielding of the material in the region \((b - 2\eta t)\) causing a sudden drop in the stiffness of the plate in the ratio of \(2\eta t/b\) at the axial load equal to \((\sigma_y - \sigma_r)\) but the load-carrying capacity of the
Fig. 7. Simply supported plates with initial deflections, edges restrained, under longitudinal compression, effect of initial deflection shape on plate behaviour, $W$ - plate central deflection.
Fig. 8. Simply supported plates, edges restrained, with initial deflections and residual stresses, under longitudinal compression

Fig. 9. Plate with residual stresses under tensile or compressive loads, $\sigma_r$, residual compressive stress, $\sigma_y$, yield stress
plate is again the same when the axial strain is sufficiently large (twice the yield strain). The same phenomenon occurs in plates having both initial deflections and stresses. The sudden drop of the stiffness is now expressed by a "cutting off" of the extreme part of the plates equilibrium paths, especially in plates which have clearly marked extreme points. This particularly pertains to plates having initial deflections which are not sympathetic with buckling mode deflections what is the case with the rectangular plate whose equilibrium path is given in Fig. 8.

Conclusions
Simply supported and clamped square and rectangular plates were analyzed to study the effect of in-plane boundary conditions and imperfections (initial deflections and stresses) on their load - carrying capacity under uniaxial compression. Restrained displacements of edges of plates middle planes (no possibility to move in after plate deflection) increase considerably plates ultimate strength. Most affected are simply supported and slender plates. Initial deflections only then decrease ultimate strength of plates when their geometric shape is sympathetic with the shape of the buckling mode. Initial compressive stresses decrease ultimate strength of plates considerably only if the plates have clearly marked extreme points. This pertains to plates having initial deflections which are not sympathetic with their buckling mode deflections.

Initial plate deflections are not normally distributed and have very complicated geometric shapes. In the shape dominates the first harmonic term \( \omega_{o(1)}/t \). The average of the maximum relative deviation from plate flatness \( \omega_{o_{max}}/t \) as well as of the first harmonic \( \omega_{o(1)}/t \) and the buckling mode components \( \omega_{ob}/t \) increase linearly with the slenderness \( b/t \). Also linear relationship holds between the mean of the buckling mode components and the plate aspect ratio \( a/b \) but \( \omega_{ob}/t \) decreases with the increase of \( a/b \).

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ABSTRACT

In December 1991 several full scale ship collision tests were carried out in the Netherlands. One of the initiators was the Dutch Ministry of Transport and Public Works. This paper describes the Dutch risk assessment and risk management policy, concerning inland waterway transport and especially that of hazardous material. After an introduction, section 2 deals with the Dutch risk management policy, section 3 discusses various aspects of risk assessment, and in section 4 the role of the full scale tests is described. In the last section the future plans are outlined.

1. Introduction.

Why has the Dutch Ministry of Transport and public works spent a lot of work and paid a substantial amount of money to contribute to a collision of ships while its policy is to promote the safety of transport on inland waterways? For an answer to this we have to go back in history.

In the Netherlands, during the middle eighties there was a serious discussion about the acceptability of the transport of goods over the main Dutch waterways by means of six barge push tow vessels.

There was concern about the manoeuvrability of these units. Would the introduction of six barge push towing lead to more collisions with bridge piers and ships and what was the risk for the penetration of dikes?
After thorough research [1] an agreement was reached. At first as an experiment and under certain conditions, permission was given in 1986 for the waterway from Rotterdam to Germany, in the confidence that the current level of safety would not be affected. However this raised questions about this current level of safety and whether this was sufficiently low. These questions where asked to the minister of transport by an advisory committee of "three wise men". The minister decided to dedicate a thorough research to the subject.

As a part of a long term Dutch national planning on Traffic and Transportation (Structuurschema Verkeer en Vervoer) the project "Veiligheid Vervoer over Water" (Safety of Inland Waterway Transport) was started in 1988.

Because of the impact of accidents with hazardous materials, in this project special consideration has been given to such transport although accidents with these ships are very rare in the Netherlands, especially during navigation. The risks for surroundings and environment as a result of the loading and unloading of ships from and to land-based installations, which actually are an important part of the transport process, are not considered in this project. The main reason is that legislation for these handling activities is not under the jurisdiction of our ministry, while naturally transport is. And transport brings the hazardous material near people in residential quarters; their safety is one of our most important concerns.

The various possibilities for a further improvement of the safety level are studied as well as the prospects of a developed Risk Assessment Model. This model will show the results of the implementation of safety measures separately or in combination. This is not an easy task, as in general we can say that apart from potential bottlenecks where safety might indeed be significantly low, the safety level of the transport over inland waterways is already very good.

This is mainly due to:
- The special education needed to transport dangerous goods. On all Dutch inland waterways the international regulations for
the transportation of hazardous materials for the Rhine, drafted by the Central Committee for the Rhine in Strasbourg, apply, according to the Treaty of Mannheim and the Dutch legislation on the transport of hazardous material.

- The traffic control systems (Vessel Traffic Services)
- The quality and equipment of the ships (due to international Rhine regulations of the CCR)
- The low speed of ships

But the transport of hazardous materials is growing. Bulk transport in ships is not the only mode. As a result of international developments, combined transport, and the policy in many countries (Netherlands, Germany) to move goods from the road to rail and inland waterways more hazardous materials will be carried in ships and many of these goods are stored in smaller quantities in containers. One Europe-containership can carry as many as 75 to 80 times as much as trucks can contain. It is expected that containers are even safer than tankships, but it is not clear how the risk levels will change with a possible increase of transport volume. This underlines the necessity of the "Safety of Inland Waterway Transport-project".

Despite the relatively good safety prospects of inland waterway transport, the waterway transport risks are given seemingly exaggerated attention. This is not so much for the high probability of a severe accident, for this probability is not high at all. But if an accident occurs and there is loss of hazardous material, the possible impact of such an event might be socially unacceptable. Because of the large quantities of hazardous materials that is transported, the possibility that many fatalities result is not entirely theoretical.

It is, therefore, with transport quite the same as with fixed installations: there are to be limits on their allowable risks. Especially risks for people outside the system, people living on the banks near the transport waterways or people living near industries, are to be finite and small enough. But how small are they to be? And how are fixed installations to be compared to
transport routes? In the next chapter we will briefly discuss this matter.

2. Dutch risk management policy.

Within the framework of the National Environmental Policy plan the note "Omgaan met risico's" (risk management) was published. It described the way to deal with risk in the case of new residential quarters near risk sources, or in the case of new risk sources near existing living areas. The general philosophy behind the note was that building new residential quarters near industries puts limits on the possibilities for design of the quarters, whereas new industrial risk sources were to be safe enough as not to put risk on people already living there, beyond a certain limit. Naturally, as far as there are (potential) problems in the field of physical planning, this philosophy yields massive cooperation with provinces and communities if necessary, because often there are conflicting interests.

However, the risk limits of the Dutch Department of Environment contained in the note, were not made for mobile sources of risk, such as the transport of hazardous materials, but for fixed installations. Fortunately, the risk dimensions used are still quite useful to transport problems. In fact, in the note two risk dimensions are used, of which one (the individual risk) can be applied to transport without problem. The other is group risk, which shows the probability of an accident with many fatalities. For individual risk, which is the probability of death for someone staying permanently at any certain spot, the limits of risk because of fixed installations can be directly applied to transport. For group risk, the limits for fixed installations could not (easily) be applied to moving risk sources over long distances.

Therefore, one of our many sub-projects called risk limit development for the transport of hazardous material, considers 3 possibilities for a transport group risk dimension at the moment: - norms for a fixed part of the waterway of 1 km.
Presently, we are still far off a choice between one of them. First a "consequence-research" is being carried out, to clarify the implications of any of them, and of the choice of the final risk limit value. In the mean time it is still possible to try to establish the current risk levels along the Dutch waterways. Even without settled risk limits, it is possible to calculate and compare risk values. In the next paragraph we will briefly show how this is done.


For all the main Dutch inland waterways a study has been carried out, showing the risk-contours and possible bottlenecks that deserve further consideration. In [2] the results of this study are outlined. The method that was used is described in [3]. Here we will only give a brief overview.

1. From accident casuistry the probability of an accident on a specified part of a waterway is assessed. Only accidents with transport vessels are taken into account, and only sufficiently severe accidents are used.

2. The registered transport volumes of several distinguished classes of hazardous materials (in single or double hull ships) is used to calculate the probability of a severe accident with a ship carrying such cargo. This can be done because in the Netherlands as a result of agreements with trade and industry and regulations there are reporting and tracking systems where information about ships carrying dangerous goods is collected and (confidentially) kept. Also registration at locks is used.

3. Given a hypothetical accident with a hazardous cargo ship, the probability of loss of containment (for single hull or for double hull ships) is used to calculate the probability of a toxic or
explosive cloud, a flammable pool of hazardous material on the water, and a few more scenario's. The probabilities of loss of containment are only estimated thus far. For single hull ships a reasonable guess was made using casuistry of loss of containment, but for double hull ships, the used probabilities were only agreed upon between shipping industries and our ministry, but these values were by no means proved to be right.

4. With the calculated probabilities of occurrence of toxic clouds a probability of death (POD) can be calculated for locations on the banks near the waterway. These calculations involve many parameters, among them wind speed, wind direction and wind stability. For flammable and explosive materials one more stochastic variable is needed, namely the probability of ignition, but essentially calculation of POD goes along the same lines as with toxics.

It is because of the uncertainties in the probability of loss of containment for double hull inland waterway tankers, that our ministry had to go through a long trajectory of research, that has almost reached its end with the full scale collision test.

4. The role of full scale tests.

As we have shown before the probability of fatal accidents (i.e. accidents which lead to loss of containment) with double hull ships is rather low. The information available about actual accidents is insufficient to make a right judgement of the possible safety measures to limit risks. In fact, up until now no such accidents were ever registered in the Netherlands, though for single hull ships fatal accidents indeed (but rarely) occur. As the impact of loss of containment from double hull ships is much more severe than when a single hull ship is damaged (because of the nature of the cargo), we cannot just estimate the probability of such an accident to be zero. Therefore it is obvious that it is necessary to estimate this probability.
In the Safety of Transport on Inland Waterways-project different types of measures have been chosen that can contribute to safety. Moreover a Risk Effect Model (REM) is under development with which the application of these measures can be made visible. One of the measures under consideration is legislated use of double hull ships for several kinds of cargo that currently may be transported in single hull ships. But as long as it is not clear what effect such a measure has on the calculated risk, it is possibly premature to decide upon it.

On the other hand it is not unthinkable that some time in the future several kinds of hazardous material that are now not allowed in ships at all, may be transported in double hull ships. To decide upon this, the safety of those ships has to be known.

Therefore there was a need to estimate the probability of loss of containment for double hull inland waterway tankers. We started our research in this direction by calculating the mechanical damage on a double hull tanker, caused by a collision. The MacNeal Schwendler Company (MSC) carried out these simulations (eight in all) [4]. The method that was used was, however, not generally accepted as absolutely to be relied upon. Especially the shipping industry requested verification of the method, as the implications of the result of MSC might be far reaching. We saw only one possibility for verification, namely a full scale collision test.

Such a test would, of course, wreck two ships, possible beyond repair, and this would cost millions. However, as there is a special demolition regulation, according to which only after demolition of an old ship, a new ship can be built, it was possible to organise the collision test at much lower cost.

Still, the plan seemed to be too expensive to be worthwhile, but when CMO showed interest, and participation of the Japanese shipbuilding industry became probable, the wild ideas were finally put into practice, and were indeed carried out by TNO-CMC.

Several collisions were carried out with different side structures of the struck ship and different speeds of the striking ship,
showing the differences between the resistance of single and double hulls. The data were carefully stored and filmed and are used again in the MSC numerical simulation method.

Now that the calculation methods, used by MSC, are validated, the next step will be the derivation of a probability distribution of the volume of loss of containment, given a severe accident with a double hull ship. This step is currently being carried out, and involves the results of all calculations of MSC, but also a thorough screening of the Dutch database of registered accidents in navigation, to find out the distributions of speeds, mass, angle of impact, and several other influencing factors. Only when this project is concluded, and the calculated loss of containment according to MSC's results is transformed into a real life over all distribution of loss volumes, we can resume our risk assessment with a new approach for the safety of double hull tankships.

5. Conclusion

The results of these simulations and unique collision tests are very important for trade and industry and the authorities. Instead of estimations solely based on haphazard casuistry, additional information about instrumented collisions is now available. The results will be the basis for the consideration of the necessity of certain provisions concerning double hulls, if a risk analysis shows bottlenecks, either in space, in category of hazardous material, or in type of ship.

Some measures can be taken at a regional or national level, others need an international unanimity, such as the ADNR-regulations. To get such a unanimity, convincing facts are necessary. A new ADNR is due at the beginning of 1993. For the European inland waterways where the ADNR is not applicable there will be new ADN-recommendations (based on the revised ADNR) of the United Nations (Inland Transport Committee of the Economic Commission for Europe) shortly after the new ADNR comes into force.
Especially Dutch trade and industry is anticipating on these new regulations. Double hull-ships will be able to take also the cargo that will no longer be permitted in single hull-ships. The validated simulation model, together with the Risk Effect Model will prove that the transport of hazardous material on inland waterways is a very safe mode of transportation.

The ship collision experiment has been an important contribution to navigation risk management and the policy concerning the transport of dangerous goods in the inland navigation.

References


R & D Program on Protection of Oil Spill from Crude Oil Tankers
H. Ohtsubo

1. Current Status of Oil spill from tankers

According to the statistics of tanker accidents and oil spill

(1) The oil spill is decreasing in these 10 years as a general tendency, except for several bumps of major accidents.

(2) The ratio of oil spill from tankers by accidents to the total inflow of hydro-carbon

In 1985, 12.5 % of inflow was due to the oil spill from tankers by accidents, according to the research of National Research Council. In 1991, the ratio is only 5 %, according to the USCG. Total inflow of 1991 is 2.3 million ton.

(3) Main causes of the oil spill from tankers are grounding, collision, fire, explosion.

(4) Major portion of the amount of oil spill from tankers is from large accidents.

A few very large oil spill accidents account for 95 % of total amount of oil spill. (NAS)

2. Preventions and regulations

(1) The regulation for these 20 years are as follows

’71 Limitation on tank size
’73 SBT
’78 PL (Protective Location)
IGS (Inert Gas System)

These regulations are decreasing the amount of oil spill, judging from the statistics of accidents.
(2) New regulations

<table>
<thead>
<tr>
<th>Newly Built Tankers</th>
<th>#32 MEPC, IMO</th>
<th>OPA'90</th>
</tr>
</thead>
<tbody>
<tr>
<td>which has the contract date</td>
<td>In or after July 93~</td>
<td>In or after June 90~</td>
</tr>
<tr>
<td>or the delivery date</td>
<td>In or after July 96~</td>
<td>In or after Jan 94~</td>
</tr>
<tr>
<td>Tanker Type</td>
<td>DHS or MDT</td>
<td>DHS</td>
</tr>
<tr>
<td>Existing Tankers</td>
<td>To be upgraded after 25 years, or phased out (for pre MARPOL)</td>
<td>SH will be used until 2010</td>
</tr>
<tr>
<td></td>
<td>To be upgraded after 30 years, or phased out (for post MARPOL)</td>
<td></td>
</tr>
</tbody>
</table>

Many new ships will be DHS, since only DHS is allowed in US water by OPA'90. Existing ships will be scrapped at 25 or 30 years old or earlier and inspection is intensified.

(3) Effects of new regulations
Will these regulations truly effective to the oil spill? Some studies have been done on this matter.
- The analysis of effectivity against oil spill by MEPC (IMO)
- Statistics of fire and explosion by LR
- The remaining strength analysis after grounding by ABS
- Oil spill experiment on DHS and MDT by DTMB and Tsukuba Institute SOF

(4) The impact and influence to the structural design of tankers
For new tankers
1. Large vessel size
2. Complex and heavy structure
3. Decrease of safety against fire and explosion
4. Decrease of productivity
5. Cost up
6. Bad maintainability

For existing tankers
1. A large scale repairing
2. Intensified inspection and recording
3. Shorter life span
(5) Direction of the regulation to ship structure

**OPA'90**

employed fixed design standard, DHS, rather than performance standard.

**IMO**

established new aspect by the introduction of MDT as an equivalence of DHT based on the comparative study.

By the evaluation of the amount of oil spill for several designs by analysis and experiment, IMO employed "performance standard".

3. Research and Development

(1) Establishment of accidents database

The need of structural damage specific database that tells the extent and conditions of failure, not only general, obscure database.

Since many accidents occur every year, the specific database should be proposed in urgent.

(2) Failure Behavior of the Structures

The need to know the mechanics of failure in ship structure due to grounding and collision.

(i) The mechanics of initiation and propagation of failure needs to be clarified. Also, the size of damaged area needs to be predicted. These depend on the type of structural design, configuration of the members, material, welding method. These elementary studies are to be used in computer simulations.

(ii) The behavior of the failure of inner hull which actually causes oil spill, following to the failure of outer hull needs to be clarified.

(iii) The understanding of actual behavior by large scale dynamic experiment is necessary because of the dynamic effect on buckling, strain rate effects and effect of plate thickness on the material property, minimum size of weld leg length.

(iv) The establishment of prediction method using computer simulation is desirable.

(3) Outflow behavior

The outflow behavior from damaged area is essential to evaluate the effectiveness of a structural design when accidental condition was given. The location of tanks, draft, characteristics of oil need to be considered. Also secondary outflow due to tidal level change and tidal current.

The experimental data of IMO should be analyzed, and the main objectives for R&D work should be clarified.
(4) Structural deterioration and risk of accidents

The intensified inspection and obligatory record keeping for existing ships and upgraded ships enable the collection of structural inspection data worldwide. The evaluation of the results is an important R&D subject, in the aspect of estimating the risk of accident. The evaluation of the effect of structural deterioration, corrosion and fatigue, on the grounding, collision, and remaining strength is important, as well as on the fire and explosion.

The risk assessment method in other field such as nuclear engineering might be of use.

(5) Remaining Strength after Accident, Restoration

The estimation of the residual strength is important in the respect to preventing pollution by sinking, capsizing, and large secondary accidents. Are there good methods to estimate the relation between resisting force and extent of damage or absorbed energy?

(6) New Structural Design Method

The clarification of the behavior and establishment of predicting method stated above (1)-(5) enables new structural design. With existing technology, how far could we make structural design that will resist collision and grounding?

The review should be made in the respect of new design method, and desirable direction should be set. The new structural design and material might result in the more effective pollution prevention. The current situation and new direction should be reviewed in this respect too. For the purpose of preventing large scale oil spill, the proposal should be made that will prompt the improvement and progress of the technology by maintaining the freedom of structural design.


(1) Purpose: Propose methods to estimate the extent of structural damage and to predict expected value of oil outflow. The expected value of oil outflow may be used as performance standard measure in comparing several designs for tankers.

(2) Schedule (tentative for 1993 and after)
     (i) Experimental Studies
        Dutch-Japanese full scale collision tests
        Experiments for bottom raking damage
     (ii) Numerical Simulation
        · Prediction of oil outflow from damaged tanks (1992-1994)
        · Probability analysis of collision and grounding (1992-1995)
        Establishment of database
        Detail of structural failure, Absorbed energy
(3) Study on Structural damage

- Experiments for exclusive tanker structure are performed to examine the characteristics of failure of them. Former studies were mainly on nuclear powered ships, general cargo ships, and LPGC etc.

- Full-scale models or large scale models are used to avoid the effects of uncertainty of scaling, possible change of material property and difficulty in scaling of weld.

- Numerical simulation is carried out to verify its applicability for grounding and collision and the necessary data such as critical strain for rupture of plates and welding lines for simulation is obtained by comparison with experiment by simple structure models.

5. Conclusions

It is new standpoint to design ship structure for the purpose of preventing ocean pollution.

There is need to flexibly make the new structural design method to resist collision and grounding, and to prevent large oil spill.

For that, new R&D work to clarify the behavior of failure and outflow of oil is essential.

Based on that data, the establishment of numerical simulation or estimation method is needed.

ASIS started R&D project in 1991 for the purpose mentioned above.

The evaluation of healthiness of structure based on the inspection data, and risk assessment approach is also needed.
Study on Damage of Ship Bottom Structure due to Grounding  
T. Kuroiwa, Y. Kawamoto, T. Yuhara

1. INTRODUCTION

1.1 Protection of Oil Spills from Tankers

In March 1989, the EXXON VALDEZ ran aground in Alaska, spilled about 36,000 tons of crude oil and caused disastrous pollution of sea environment. After the accident, protection of oil spills from tankers became one of the great concerns of the world. The new regulations on oil tankers were established by International Maritime Organization (IMO) and the congress of USA to prevent sea pollution.

In Japan, the Association for Structural Improvement of Shipbuilding Industry (ASIS) started the 7 years research project on 'Protection of Oil Spills from Crude Oil Tankers' in 1991 with support from the Japanese Ministry of Transport.[1]

In the research project, structural failures of ships due to groundings and collisions, oil outflow from ruptured tanks and so on are being studied. The present study is one of the results obtained in the first year of the Japanese project. MHI was entrusted by ASIS with carrying out the study in 1991 and on behalf of ASIS authors present the results.

The other major result is the Dutch-Japanese Full-Scale Collision Tests.[2][3]

1.2 Structural Failure due to Groundings and Collisions

From view point of structural strength, the following three failure modes are important to prevent oil spills from tankers in case of collisions and groundings, because those structural failures inevitably cause oil outflow.

(1) Rupture of Inner Side Shell due to Collision
(2) Rupture of Inner Bottom Shell due to Grounding
(3) Bottom Raking due to Grounding

The present study is on the item (3) and the Dutch-Japanese Full-Scale Collision Tests are on the item (1). The item (2) will be studied in the Japanese project by ASIS.

1.3 Bottom Raking due to Grounding

In case of grounding, the length of ruptured bottom, in other words, the number of ruptured tanks determines the amount of spilled oil. (Fig.1) In the accident of the EXXON VALDEZ, the bottom was raked along almost whole length of ship and caused major oil spill. Therefore, it is important to know the length of
bottom raking beforehand to estimate the expected amount of oil outflow and to evaluate several designs of ship's bottom.

The length of bottom raking $L$ is determined on the concept of energy balance that the ship moves forward until all of the kinetic energy of the ship is absorbed by the structural failure of the bottom.

$$L = \frac{E_k}{F}$$

where $E_k$ is kinetic energy of ship including added mass effect and $F$ is mean raking force to destroy bottom structure of ship.

In this study, experiments and numerical simulations were performed to study the structural behavior of bottom raking and to evaluate the raking force $F$.

2. EXPERIMENTS

2.1 Structural Failure of Tankers

Several studies have been performed on the raking damage of bottom structure.[4][5] The objectives of those studies were nuclear propulsion ships and general cargo ships. However, the design of oil tankers are different from those ships, for example, the stiffeners of oil tankers are more widely spaced compared with those ships in general.

To examine characteristics of the structural failure of oil tankers, experiments were carried out using two models of bottom structures of VLCCs (very large crude carrier). One is for single bottom and the other is for double bottom.

2.2 Scaling

The former studies used small models, for example, 1/10 of full-scale.

The scaling law in structural failure is not simple. The strain energy absorbed by plastic deformation is proportional to $\lambda^3$ while the energy absorbed by rupture is proportional to $\lambda^2$,

where $\lambda$ is scale factor to the full-scale. ($\lambda<1.0$) In the failure of ship structure, plastic deformation and rupture occur together. So the scaling factor of energy is between $\lambda^2$ and $\lambda^3$ and it is dependent on the failure mode. [6][7]

Furthermore, there are some other points to be considered in the experiments using scale models. The thin rolled steel plate (e.g.2mm) has generally high yield stress and large elongation at rupture than thick plate (e.g.20mm). Also, it is difficult to scale welding line precisely on the scale model with thin plate.

Therefore, the experiments with thin plate models have a possibility that those would not be able to represent the actual failure of ship structure.

Taking account of the above considerations, it is desirable to do the experiments with large scale model. In the present tests, 1/3 scale models are employed from the limitation of the capacity of a test apparatus.
2.3 Method of the Tests

Fig. 2 shows a sketch of the experiments. A wedge shaped rigid rock model, fixed to a press machine, was pushed against the bottom model along the direction of ship length quasi-statically. As mentioned before, two models with 1/3 scale were tested. The dimensions of the models are shown in Fig. 3. The models were made by steel plate, the yield stress of which were 33 kgf/mm² on average. The leg length of welding was also scaled by 1/3 and for these models it was 3mm wide.

Raking force \( F \), penetration length and displacement and strain at several points were measured.

2.4 Results and Consideration

The raking forces vs. penetration length are shown in Fig. 4, in which structural behavior during the tests are described together. Fig. 5 through Fig. 8 show some pictures taken during and after the tests.

To predict the raking force \( F \), the following equation is often used.

\[
F = \alpha \Sigma (\sigma_y \cdot A)
\]

(1)

The formula is a kind of Minorsky method with empirical constant \( \alpha \), yield stress \( \sigma_y \) and area \( A \). \( A \) is a sectional area of a longitudinal member, measured in the plane perpendicular to the direction of ship length. \( \Sigma \) means sum of the members. As the empirical constant, \( \alpha = 0.8 \) was determined from the experiments for general cargo ships.

For the present experiments, the approximate raking forces, obtained from equation (1) using \( \alpha = 0.8 \), are about 60% and 70% of the measured maximum forces as shown in Table 1.

One reason of the discrepancies may be the structural characteristics of VLCC, which has wider space between stiffeners and between trans. rings. The other reason is the shape of the rock model. Each of those two factors have the effect by which the stiffeners are easily bent before compressed. This means that the stiffeners can not bear enough force expected in equation (1).

To distinguish force borne by bottom plates and borne by stiffeners, equation (2) was proposed.

\[
F = \alpha_p \Sigma (\sigma_y \cdot A)_p + \alpha_s \Sigma (\sigma_y \cdot A)_s
\]

(2)

In the modified formula, subscript \( p \) and \( s \) represent bottom plates and stiffeners respectively, and empirical constants are defined for plates \( (\alpha_p) \) and stiffeners \( (\alpha_s) \) separately.

Substituting the raking forces \( F \) measured in the present tests for two models, yield stress \( \sigma_y \) and sectional area \( A \), we have constants as shown in Table 2. It is found that the constant for plate \( \alpha_p \) is 0.8 as usually used, but the constant for stiffeners
\( \alpha_s \) is 0.3, which is far smaller than 0.8.

In the bottom structures of tankers, the stiffeners may be bent easily and the raking force may be smaller than expected previously. However, further studies will be needed to make sure, because only two tests have been performed.

3. NUMERICAL SIMULATION

3.1 Purpose

It is useful to employ numerical simulations in comparing the raking force \( F \) for several possible designs of ship's bottom. With the development of computer hardware and software, it may be cost effective to perform several simulations than to carry out same numbers of experiments.

Moreover, it is sometimes difficult to carry out experiments which simulate real accident. Numerical methods will be suited for the purpose.

In this study, numerical simulations were performed using MSC/DYNA, explicit transient finite element method. And the capability of the numerical method was investigated.

3.2 Method of Simulation

The bottom structures were modeled by finite elements as shown in Fig. 9. Taking account of their symmetry, 1/2 of the single bottom structure and 1/4 of the double bottom structure were modeled for the simulations.

The supports for the bottom structures in the experiments were rigid enough, so the fixed boundary conditions at the supports were given for the simulations.

The material properties such as Young's modulus, yield stress and breaking strain were obtained from material tests for the plates used in the experiments. The rupture condition for the simulations were given only at the center line of the bottom structures, the line along which the right angle edge of the rock model passes.

Contact between the bottom model and the rock model and contact between each part of the bottom structures were considered. Friction associated with the contacts were taken into account. The friction constant was presumed to be 0.3.

In the experiment, the rock model moved quasi-statically. However, in the numerical simulations, the moving speed of the rock model was given to be 6.0m/s to reduce the computational time. The speed of 6.0m/s is so small that the stress wave in the bottom models caused by the impact would not exceed 24kgf/mm², which is about 2/3 of yield stress of the plates of the bottom models.
3.3 Results

Deformations of bottom structure obtained by the simulations are shown in Fig.9. The deformations are in good agreement with the experimental ones.

In Fig.10 and Fig.11, the numerical results are compared with the experimental ones. The energy absorbed by bottom structures (E_b) were simulated within 20% error compared with the experimental results as shown in Fig.10.

The raking force by the simulation have some sharp peaks, which are considered to be numerical spikes. Maximum raking force, excluding the sharp numerical peaks, were about 30% higher than experimental results. (Fig.11)

One of the reasons of the difference is that a failure of fillet welding were not considered in the numerical simulations. In the experiments, some failures of the fillet welding between stiffeners and bottom shells and between webs and faces of stiffeners were observed as shown in Fig.8. Appropriate modeling of fillet welding is one of the subjects to be studied in the future.

4. CONCLUSION

Using 1/3 scale model of bottom structures of VLCC, the experiments, which represent bottom raking due to grounding, were carried out. It is observed that the raking force F to destroy the bottom structure is smaller than expected from the existing approximate formula. The difference may be caused by the structural characteristics of VLCC, which has wider spacing between stiffeners and trans. rings, and the shape of rock model. By those factors, stiffeners can not bear large force.

Parametric study on stiffener space and size, and study on shape of rock will be done in the future.

Numerical simulations estimates the energy E_b within 20% error and show promising capability in predicting structural damage of tankers.

In the numerical method, there are some points to be improved, for example, failure of fillet welding between stiffeners and bottom plates. Those will be improved by further study.

(This paper was presented in the First Joint Conference on Marine Safety and Environment/Ship Production, 1-5 June 1992, Delft University of Technology, the Netherlands)

Table 1  Maximum Raking Force
Comparison between Experiments and Equation (1)

<table>
<thead>
<tr>
<th></th>
<th>Single Bottom</th>
<th>Double Bottom</th>
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</thead>
<tbody>
<tr>
<td>Experiments</td>
<td>240 ton</td>
<td>410 ton</td>
</tr>
<tr>
<td>Equation (1)</td>
<td>402 ton</td>
<td>601 ton</td>
</tr>
</tbody>
</table>

Table 2  Empirical Factors in Equation (1) and (2)

<table>
<thead>
<tr>
<th></th>
<th>Shell Plate</th>
<th>Stiffener</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation (1)</td>
<td>$\alpha = 0.8$</td>
<td>$\alpha_s = 0.3$</td>
</tr>
<tr>
<td>Equation (2)</td>
<td>$\alpha_s = 0.8$</td>
<td>$\alpha_s = 0.3$</td>
</tr>
</tbody>
</table>

736
Fig. 1  Bottom Raking due to Grounding  
L is the length of bottom raking.

Fig. 2  Schematic View of the Experiments  
Rock model is pushed against bottom model quasi-statically  
along the direction of ship length.
Bottom Stiffener \([W250 \times 6 + F70 \times 9 (T)]\)

(a) Single Bottom Model

Bottom Stiffener
[Inner Bottom Plate \(W150 \times 6 + F70 \times 9 (T)\)]

(b) Double Bottom Model

Fig. 3 Section of Bottom Models
Fig. 4  Raking Force vs. Penetration Length by the Experiments
Fig. 5 Tearing of Bottom Plate of Single Bottom Model.
(Penetration Length: 925mm, Raking Force: 208 tonf)

Fig. 6 Tearing of Trans. Ring Bending Deformation of Stiffeners of Single Bottom Model
(Penetration Length: 925mm, Raking Force: 208 tonf)

Fig. 7 Tearing of Floor.
Taken from the Inside of Double Bottom Model.
(Penetration Length: 1200mm, Raking Force: 296 tonf)

Fig. 8 Failure of Fillet Welding Stiffener of Single Bottom Model
(a) Single Bottom
Penetration Length: 990mm, Raking Force: 250tonf

(b) Double Bottom
Penetration Length: 1060mm, Raking Force: 480tonf

Fig. 9 Results of Simulations
Deformations of trans. ring, floor and stiffeners
shows good agreements with the experiments
Fig. 10 Absorbed Energy vs. Penetration Length
Comparison between Experiments and Simulations

Fig. 11 Raking Force vs. Penetration Length
Comparison between Experiments and Simulations
ABSTRACT

Several calculation methods are available to determine crush worthiness of ship structures. However, no full scale experimental data was available which could be used to verify these methods. This paper describes a series of four collision experiments which were carried out with two inland waterway tankers of approximately 1000 Tonnes displacement. At each experiment a nearly rigid bow struck the side of the victim at a right angle. Three types of side structure were tested; single side, double side with stringers and double side with stringer deck. Collision forces, motions and penetration depths were measured during the collisions as function of time. Salient details with regard to the design and the execution of the experiments are presented in this paper. Some test results are included as well.

INTRODUCTION.

Inland waterway navigation in Europe is becoming increasingly important. However, for safety and environmental reasons, several bulk chemicals are not allowed in inland vessels. The Dutch government is carrying out a research study concerning the general safety and environmental risk of inland waterway traffic [4]. One object of this study refers to the risks involved when calamities with ships such as collisions and/or groundings occur. Here the crush worthiness (energy absorbing resistance) of the ship structure is of interest.
Particulars of struck ship "BORIS".

General particulars.

Table 1 shows the general particulars of the struck ship.

Table 1 General geometrical data of struck ship "BORIS".

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<thead>
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<th>Value</th>
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<tbody>
<tr>
<td>Length over all</td>
<td>80.05 m</td>
</tr>
<tr>
<td>Beam</td>
<td>8.21 m</td>
</tr>
<tr>
<td>Draught Min.</td>
<td>0.71 m</td>
</tr>
<tr>
<td>Draught Max.</td>
<td>2.62 m</td>
</tr>
<tr>
<td>Displacement Min.</td>
<td>389 Tonnes</td>
</tr>
<tr>
<td>Displacement Max.</td>
<td>1528 Tonnes</td>
</tr>
</tbody>
</table>

The struck ship "BORIS" was fitted with 10 cargo tanks. The tank arrangement shown in figure 1.

Structural arrangement in way of strike locations.

The BORIS was built as a single side ship with one longitudinal bulkhead at centre line. It is important to note that the ship was converted into a tanker a later date, so material properties of the deck and the side of the ship differ slightly from the material properties of the upper part of the trunk and the trunk deck. Also the original hatch coaming was extended with an additional trunk which runs up to the trunk deck (tank deck).

Beside two collisions into a single side structure there were also two collisions into a double side structure. These double side structures were specially built for this purpose. They were fitted along the length of tank 2 on port side and tank 3 on starboard.

Figures 2 and 3 show the structural arrangement of a single side and a double side structure.
The past has shown the environmental risks of crude oil transport by sea going tankers. Several proposals were made aiming to prevent oil outflow when damage to a tanker occurs [5]. In the U.S.A. a double hull structure is already compulsory. Once again the crush worthiness of the ship structure is of paramount interest.

VRO ships are extremely vulnerable with regard to their hydrostatic stability when damaged. The extent of the damage caused by either a collision or grounding is of great importance [6]. So here also the crush worthiness of the ship structure is of importance [6]. Fortunately several calculation methods are available to determine crush worthiness. Many experiments were carried out for verification purposes. However full scale experimental data was available which could be used to verify these methods [1], [2], [3].

In order to generate full scale data, a series of four collision experiments was carried out with two inland water way tankers of approximately 1000 Tonnes displacement. The results of two of these experiments are reported here.

The experiments were carried out by the Centre for Mechanical Engineering of the Netherlands organisation for applied scientific research (CMC-TNO). Computer simulations were carried out by the MacNeal Schwendler Company. The Netherlands foundation for the Coordination of Maritime Research in the Netherlands (CMO), acted as principal. The project was sponsored by the Japanese association for the structural improvement of the shipbuilding industry (ASIS) represented by Mitsubishi Heavy Industries (MHI). Other sponsors were the Netherlands ministry of transport and public works (Rijkswaterstaat) and the Netherlands central bureau for navigation on the Rhine and inland waterways (CBRB).

Fortunately the engineering with regard to stability (damaged and intact) of the ruck ship, strength of the ship's girder of the damaged ship and strength in way of the load transducers on the striking ship, cannot be attended to within the scope of this paper.

\[1\] In damage stability calculations the 1/5 B criterion is very important. However this value is not based on any crush worthiness considerations.
Figure 1 General arrangement of striking "RANCO" and struck ship "BORIS", strike locations are indicated.
Figure 2 Single side structure of struck ship tank 4 FS, tested in test number 2.
Figure 3 Double side structure of struck ship tank 3 SB, tested in test number 4.
ticulars of striking ship "RANCO"

General particulars.

General geometrical data of the striking ship "RANCO" are listed in table 2.

Table 2 General data of struck ship "RANCO".

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length over all</td>
<td>79.92</td>
<td>m</td>
</tr>
<tr>
<td>m</td>
<td>8.20</td>
<td>m</td>
</tr>
<tr>
<td>Ught Min.</td>
<td>0.64</td>
<td>m</td>
</tr>
<tr>
<td>Ught Max.</td>
<td>2.48</td>
<td>m</td>
</tr>
<tr>
<td>Ught during tests</td>
<td>1.76</td>
<td>m</td>
</tr>
<tr>
<td>Placement Min.</td>
<td>351</td>
<td>Tonnes</td>
</tr>
<tr>
<td>Placement Max.</td>
<td>1447</td>
<td>Tonnes</td>
</tr>
<tr>
<td>Mass of inertia abt. long. axis Ixx</td>
<td>3841</td>
<td>Tonnes</td>
</tr>
<tr>
<td>Mass of inertia abt. transv. axis Iyy</td>
<td>369 103</td>
<td>Tonnes</td>
</tr>
<tr>
<td>Mass of inertia abt. vert. axis Izz</td>
<td>371 103</td>
<td>Tonnes</td>
</tr>
</tbody>
</table>

The bow of the striking ship was reinforced by a double plating of 15 mm welded all round. Also additional stringers were fitted. Moreover the lower part of the keel was filled with a 0.7 m high mass of concrete. So no plastic deformation occurred due to the collision forces. The anchors at the bow of the striking ship were removed prior to the collision tests.
DESCRIPTION OF TESTS.

Description of the experiments

Four deliberate collisions were carried out between two inland waterway tankers. At each collision the bow of the striking ship "RANCO", hit the side of the struck ship "BORIS" at an approximate right angle (90 degrees). In two first cases, a single side structure was tested. The third experiment aimed at testing a double shell structure with stringers. During the fourth experiment, also with a double shell, the stringer was replaced by a stringer deck between the inner and the outer shell.

During the collisions the struck ship was kept on a fixed position by anchors. Tension on the anchor lines was kept low. Therefore anchor forces could be neglected during the penetration of the striking bow.

The striking ship was self propelled. The maximum speed that could be obtained was approximately 16 km/h.

The tests were carried out in a harbour basin. There were no current and no tide at the test side. The main dimensions of the harbour were:

- length 1900 m
- width 150 m
- depth 9 m

Collision tests number 1 and 2 were carried out approximately 300 m past entrance of the harbour. The third and the fourth test were carried out at the end of the harbour. The approach procedure was the same in all four cases:

1. striking ship accelerates on the river outside the harbour.
2. striking ship turns into the harbour at the required striking speed.
3. the stretch in the harbour is used for aiming at the striking location and for some final speed adjustments.
4. striking ship starts withdrawing immediately after the collision by giving full astern.

Tests 1 and 3 are not reported in this paper.
Measured data.

During the collisions several parameters were measured. Table 3 shows a review.

Table 3 Review of measured parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration of bow</td>
<td>Penetration of bow of striking ship into the side of the struck ship</td>
</tr>
<tr>
<td>Collision force</td>
<td>Collision force between the striking ship and the struck ship during the collision</td>
</tr>
<tr>
<td>Strains</td>
<td>Strains in case of single shell: the strains at five positions along the connection of the maindeck with the trunk in case of double shell: the strains at five positions along the connection of either a stringer or a stringer deck with the inner shell</td>
</tr>
<tr>
<td>Roll, pitch, and yaw</td>
<td>All six rigid body motions of the centre of gravity of the striking and the struck ship.</td>
</tr>
</tbody>
</table>
| Surge, sway, and heave              | Metropolitan 

Collided methods of measurement and data analysis.

The penetration of the bow of the striking ship into the side of the struck ship, for reasons of redundancy, measured by means of several different devices. Two strain gauges, measuring displacement and velocity as a function of time, were fitted to the trunk deck of the struck ship. The end of each wire was fitted with magnets. The striking ship was fitted with two catching plates fitted on rods pointing forward of the bow. Slightly prior to the actual instant of contact between the striking bow and the struck side these plates would catch the magnets.
Additionally two ultra sonic displacement gauges were fitted on transverse arms at the bow of the striking ship. These devices pointed towards echo plates at the side of the struck ship. Thus an echo could be received from which the displacement as a function of time could be determined. Finally top view recordings were made with a high speed camera at the bow of the striking ship. These recordings could all be used to determine the decrease of the distance between striking ship and struck ship during the collision.

The contact force between the ships was measured directly by a series of special made load transducers, 21 in total, fitted between the reinforced bow of the striking ship and the main hull (see figure 4). In the same figure the two vertically fitted load cells, numbers 20 and 21 are shown which measured the vertical load on the bow during the collision. All load transducers were equipped with a set of four strain gauges. These strain gauges were connected into a full bridge of Wheatstone. An additional sensing wire in the measuring cables, enabled correction for the voltage drop of the source voltage along this measuring cable. The load cells were developed for 500 kN nominal load. This design load was determined on the basis of a "design"-calculation. Previous to the tests the load cells were calibrated. This was carried out in the TNO laboratory. There were calibration steps of 50 kN each. The total collision force of every test was determined by taking the sum of the 19 force transducers. So the time history of the total collision force could be determined.

Please refer to figure 5 which shows the force signals of loadcells 13 and 16 which are placed symmetrically about the ship's centerline. It should be noted that the collision forces measured and reported are the forces acting between the bow of the striking ship and the hull aft of frame 137. The actual total collision force between Ranco and Boris will be approximately 4.5 % higher because of the inertia force of the bow. The mass of the bow was estimated at 45 Tonnes out of 980 Tonnes of the whole ship.

The vertical loading on the bow of the striking ship due to the collision was measured with two vertically mounted force transducers. These transducers were the same type as the ones used for the horizontal forces. Please refer to figure 4 for the location, the direction and the connection location of these transducers.

These calculations are based on a decoupling of the degrees of freedom which describe the deformation of the structure from degrees of freedom which describe the rigid body motions of the ships.
Figure 4 Arrangement of force transducers, for collision force.
Figure 5  Example of recorded force signals of load cells 13 and 16 during collision test number 2 (see previous figure).
Rains were measured by two strain gauges per measuring location at 90 degrees. The gauges were connected into a 1/2 bridge of Wheatstone. Here also the voltage drop of the source voltage along the measuring line was measured and used to correct the measurement for voltage drop.

Rigid body motions of the ships were measured by eight accelerometers per ship. Figure 6 shows the locations of the accelerometers on the struck ship. These accelerometers were of a servo type (Sunstrand make) and very sensitive. Near both ends of each ship a set of three accelerometers was fitted each of which measured either a longitudinal, a transverse or a vertical direction. At approximately 1.5 meters two additional accelerometers were fitted in the port and starboard side ensuring in a vertical direction. The accuracy in which the accelerometers were rected was plus minus 0.1 of a degree. The accuracy necessary was obtained with tilt levels mounted on the accelerometer housings, grinded mounting plates and refull calibration on a special three degrees of freedom test bank in the laboratory. Six out of the eight accelerometers, two in each possible direction, were chosen after the time history measurements. From the six chosen acceleration histories the 'Collision Motion Monitoring Software' calculated the six rigid body motions of the center of gravity of each ship. Figure 7 shows the motions as measured on the struck ship during one of the tests.

1 measuring equipment on both ships was triggered at the same time by the eaking of two neon-light devices (every ship one device), caused by colliding. The measurement time was set at 4.096 seconds, 2048 digital measurement points with 2 millisecond sample time for test 2, 3 and 4 whereas during test 1 samples were taken every millisecond. At the time of triggering the distance between both ships (main deck level) was approximately 0.5 meters.

Additional details may be found in [8].

---

This software calculates the rigid body motions from accelerations, measured at least 6 positions of the rigid body in appropriate directions. Signal ratios may be improved by measuring at more than 6 positions.
Figure 6 Location of accelerometers in struck ship.
Figure 7  Example of measured motions on struck ship.
High speed camera recordings

High speed film recordings were made during each collision. A top view recording was made of the striking bow at approximately six metres above deck. Two recordings were made of the side (in case of a single shell) or inner side (in case of double shell), from the inside of the tanks to be collided. One recording looked forward and one looking aft. The high speed camera recordings were time calibrated therefore they could be used to determine approach velocities. Moreover relative decelerations of the striking ship with reference to the struck ship could be derived from these recordings.
TEST CONDITIONS.

Introduction.

This section presents data describing the actual test conditions valid for tests 2 and 4, please refer to table 4. Particulars which were equal for all tests are treated in the previous chapters. So ship particulars of the RANCO can be found here. Here only data is given which is specific to the tests.

Table 4 Test conditions of tests 2 and 4.

<table>
<thead>
<tr>
<th></th>
<th>TEST 2</th>
<th>TEST 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft</td>
<td>[m]</td>
<td>2.15</td>
</tr>
<tr>
<td>Long. cog from App</td>
<td>[m]</td>
<td>39.00</td>
</tr>
<tr>
<td>Transv. cog from CL</td>
<td>[m]</td>
<td>0.00</td>
</tr>
<tr>
<td>Vert cog from base</td>
<td>[m]</td>
<td>1.97</td>
</tr>
<tr>
<td>Stactentric height (GM)</td>
<td>[m]</td>
<td>1.72</td>
</tr>
<tr>
<td>Mass</td>
<td>[Tonne]</td>
<td>1242</td>
</tr>
<tr>
<td>Moment of inert. abt. long. axis [Tonne m²]</td>
<td>5308</td>
<td>5307</td>
</tr>
<tr>
<td>Moment of inert. abt. tran. axis [Tonne m²]</td>
<td>508413</td>
<td>549969</td>
</tr>
<tr>
<td>Moment of inert. abt. vert. axis [Tonne m²]</td>
<td>510969</td>
<td>552764</td>
</tr>
<tr>
<td>Collision speed</td>
<td>[km/hr]</td>
<td>14.8</td>
</tr>
<tr>
<td>Collision angle</td>
<td>[Deg.]</td>
<td>90.0</td>
</tr>
<tr>
<td>Strike location</td>
<td>[-]</td>
<td>tank 4</td>
</tr>
</tbody>
</table>

dydrodynamic properties.

Apart from surge, motions of the striking ship "RANCO" were very small. Therefore hydrodynamic coefficients of this ship are considered to be relevant only with regard to surge. With regard to the hydrodynamic properties of the ships it should be noted that the simple concept of added mass and added moments of inertia is very appropriate when semiperiodic ship motions are to be considered. However this concept is not valid for non periodic transient motions. In spite of this consideration some analysis was carried out on test results obtained from simple pull tests. Results are given table 5. Thus pragmatic figures were found for the total inertia (dry ship + hydrodynamic inertia). The pull tests were carried out on the ruck ship only.
The measured force and acceleration were simply divided in the time domain. With regard to the yaw motion the vertical axis of rotation was assumed at frame 78.

Table 5. Some hydrodynamic properties of "RANCO" and "BORIS".

<table>
<thead>
<tr>
<th></th>
<th>&quot;RANCO&quot;</th>
<th>&quot;BORIS&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>* effective mass, surge direction ((m+a_{11}))</td>
<td>1200 Tonnes</td>
</tr>
<tr>
<td></td>
<td>* effective mass, sway direction ((I+a_{22}))</td>
<td>1350 Tonne m²</td>
</tr>
<tr>
<td></td>
<td>* effective moment of inertia abt. (a_{44})</td>
<td>2100 Tonnes</td>
</tr>
</tbody>
</table>

Figure 8 shows the ratio of pulling force by acceleration i.e. the inertia. Should be kept in mind that this approach is only acceptable as an approximate one. Moreover the noise on the acceleration signals was too large to elevate the analysis to a more accurate level.

\(^5\) This is an estimated value, based on the ratio between mass of dry ship and mass of dry ship + added mass, as found from the pull test on the struck ship.
Figure 8  Inertia with respect to sway.
TEST RESULTS.

Some results of the collision tests 2 and 4 are presented here. The penetration depth as mentioned in this report is defined as the distance in athwart ship direction, at maindeck level and parallel to the trunk deck.

It was found from the measurements that the time during which penetration took place varied between 0.5 and 0.7 seconds. The following type of graphs, related to forces, are shown in this section:

- contact force vs time
- energy vs penetration and vs time

From the measurement of the penetration vs time, the duration of penetration could be obtained. Force curves are not plotted over the complete measuring period of 4.096 seconds. The reason is that the force during penetration was the main objective of the underlaying work. In Table 6 a short summary of obtained results is given for tests 2 and 4. It should be mentioned that the maximum contact force and the penetration duration are not of much importance as such. The real importance lies in the energy which was required for penetration.

Table 6 Summary of force related results of tests 2 and 4.

<table>
<thead>
<tr>
<th>Test nr.</th>
<th>Speed of collision before contact [km/h]</th>
<th>Contact force [kN]</th>
<th>Duration of penetration [msec]</th>
<th>Penetration [mm]</th>
<th>Absorbed energy [MJ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>14.8</td>
<td>3749</td>
<td>640</td>
<td>1020</td>
<td>2.6</td>
</tr>
<tr>
<td>4</td>
<td>15.6</td>
<td>5395</td>
<td>568</td>
<td>920</td>
<td>2.7</td>
</tr>
</tbody>
</table>

It is remarkable to see that during test 2, the side was deformed along the full length of the tank. In test 4 the stringer deck played a pronounced role in stiffening/strengthening the ship's side. The curves of the collision forces measured during tests 2 and 4 are shown in Figure 9. Figure 10 shows curves of absorbed energy versus penetration and time respectively. Figure 11 shows curves of velocities vs time.

Figure 12 (photographs) shows the actual final damage (deformation) to the side of the struck ship, at main deck level, caused by the collisions 2 and 4.
Figure 9 Contact forces vs time, test 2 and test 4.
Figure 10 Absorbed energy vs penetration and time respectively, test 2 and test 4.
Figure 11  Motions struck ship (velocity), test 2 and test 4.
Figure 12 Side damage test 2 (single side) and test 4 (double side).
CONCLUSIONS.

1 The collision tests carried out have been successful. The objectives of the project as listed below were achieved.

- measurement of total collision forces
- determination of collision durations
- measurement of motions of both ships during collision
- measurement of penetration depths and penetration durations
- measurement of strains in the sides of the ship due to collision.

2 The estimates made in the development phase of the project were found to be within the limits set.

3 The full scale collision experiments yield valuable information with regard to ship’s collision damage resistance. This refers especially to the behaviour of the ship’s side/deck structure when subjected to a collision with a ship’s bow.

4 The acquired test data can be used for validation of calculation methods in this field.

5 With a validated calculation method it is possible to predict penetration depths due to collisions in a single or double sided ship in relation to the speed of the vessels and their mass. Also striking forces and collision durations can be predicted.

6 In all test cases initial cracking of the shell occurred at a weld.

7 The main motions of the struck ship during collision were found to be sway and yaw. Remarkable is that almost no roll motion of the struck ship was measured.

8 Approximately only 1/3 of the kinetic energy of the striking ship is dissipated by fracture and deformation of the ship structure.

\[ ^{4} \text{The collision force has both a horizontal and a vertical component. Apparently the resulting force acted through the axis of roll rotation.} \]
9 There are two distinct subjects which are paramount with regard to further research:

- the effect of welding on the fracture initiation,
- the effect of the hydrodynamic properties of both the striking ship and the struck ship on the absorption energy.

10 It is suggested to pursue the subjects mentioned in conclusion 9 further while taking advantage of the experimental data as gathered during the project which is reported here. Especially test results should be analysed by applying the theory as outlined by Petersen [7].

11 The minimum required width of a double shell can now be determined in a rational way.

12 The 1/5 B criterium in damage stability calculations, should now be reconsidered taking into account the crush worthiness of the ship structure.

13 Calculation methods are still too laborious to be useful in design practice.

ACKNOWLEDGEMENTS.

The authors wish to acknowledge the contributions of many individuals to the project, and especially their respective wives for waiting so long while the husbands were working at late hours to keep the project within the time limit given. A special word of thanks is directed to Mr. Carlebur (CMO), Dr Kuroi (MHI), Mr. Kawamoto (MHI) and Mr. Kameyama (ASIS) for their patient attitude and the valuable discussions during the actual tests.
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[8] Vredeveldt A.W. and Wevers L.J. Full scale ship collision test results (version 03). TNO Centre for Mechanical Engineering (Building and Construction Research B-92-0279)
ABSTRACT

One of the reasons for setting up the Dutch-Japanese full scale ship collision project was the verification of a methodology that had been developed for the numerical simulation of collisions of Dutch inland waterway vessels. A total of four ship collision tests have been performed with two fully instrumented ships to obtain verification data. Each of these tests has been simulated using the numerical methodology in which the structure-structure interaction is computed with MSC/DYNA, an explicit finite-element program which enables the full simulation of the dynamics of the collision events. Fluid-structure interaction is taken into account by means of a system of springs and dampers, of which the characteristics are determined using the MSC/PISCES program.

This paper describes the numerical methodology that has been used for the numerical simulations of the full scale collision tests. For each of the four numerical simulations, the computed collision process and resulting damage will be shown. The computations were successful in simulating the main features of the collision process and the resulting damage, like hole size and penetration depth.

INTRODUCTION

Explicit transient finite-element simulation is since many years a powerful tool in the design and development process in defense-, aerospace- and automotive industry. Especially in the field of safety analysis (e.g. car-crash) this technology has been heavily used during the last few years. The use of numerical simulation allows the investigation of dynamic phenomena and also suggests directions to optimize the design of a structure. Until recently, transient dynamic finite-element analysis of ship collisions did not play an important role in safety studies for ship transport. The increasing concern regarding environmental damage and casualties as a result of ship accidents, has led to the development of a numerical methodology that has been employed
over the last two years to numerically simulate collisions of Dutch inland waterway tankers. These numerical simulations were performed to compute the amount of damage (e.g. possible hole size) for estimating the probability of a loss of cargo from a double hull tanker.

No experimental data was available for comparison and verification of the obtained results and the Dutch-Japanese full scale collision project was set up to provide this verification data for the numerical methodology.

Four full scale collisions were performed with two Dutch inland waterway tankers. The first two collision tests were carried out on an unmodified (single hull) ship and the last two collision on a modified (double hull) ship. During the third test the double hull was stiffened with stringers and in the fourth test these stringers were replaced by a stringer deck between outer and inner wall. A complete description of the experiments is given by Vredeveldt [1992].

**NUMERICAL METHODOLOGY**

**General outline**

This section will concentrate on the numerical methodology used in the ship collisions simulations. This methodology has been used for each of the four ship collision simulations and consists of three separate computations.

In a first step the collision of both ships is computed as a pure structure-structure interaction problem without the influence of the water. In this step both ships can move freely in a horizontal plane only. The collision process is computed by employing the three-dimensional explicit transient dynamic finite element program MSC/DYNA. The result of this step 1 calculation is a first estimate of the time-dependent collision force.

In a step 2 calculation this collision force is applied to a rigid (undeformable) model of the struck ship that is afloat in water. By employing the explicit transient dynamic finite difference-finite volume MSC/PISCES program, the motion of the ship under influence of the collision force is computed. This motion yields an estimate for the magnitude of the time varying water resistance force acting on the struck ship during the collision.

The step 3 calculation again with the MSC/DYNA code is the final collision calculation in which the water resistance force from the step 2 calculation is taken into account by a system of springs and dampers attached to the numerical model of step 1. During this simulation there is no constraint on the motion of the struck ship any more. Under influence of collision force and water resistance force the struck ship will have a three-dimensional translational and rotational motion.
Structure-structure collision calculation (step 1)

In this calculation the three-dimensional MSC/DYNA program is employed. This program has extensively been used in impact and penetration problems and car-crash analysis and is therefore a logical choice for the use in ship collision analysis. Available are volume-, shell-, beam- and rigid elements for the modeling of ship structures.

The ships that are investigated have a length of about 81 m and a cross-section of 8.15 m by 3.95 m. For reasons of computer time reduction, the ships are not completely modeled in detail. Only in the collision region (half of the ships width and over a length of 18 m) the struck ship has been modeled in detail with shell and beam elements as a deformable structure. The remaining part of the ship has been modeled as an undeformable rigid body.

A typical model layout is given in Figure 1. In the collision region every sub-structure of the ship is modeled in detail and all stringers, frames, stiffeners and plates are taken into account (cf. Figure 2).

Figure 1 Numerical model layout

Figure 2 Detailed numerical meshing in the collision area.
The whole striking ship is modeled as an undeformable rigid body without internal structures. The structural interaction between struck- and striking ship is computed by using a contact algorithm. The shell elements of the bow of the striking ship and the collision region of the struck ship are defined to be contact surfaces. These contact surfaces provide a very simple and flexible way of modeling the interaction between parts of the finite element model, allowing continuous contact between deforming bodies. Initially the contact surface of the bow and the struck ship are distinct and separate. At each time-step it is checked if gridpoints of the contact surface of the bow have penetrated the contact surface of the struck ship. If none have, then the calculation continues. If they have penetrated, then forces are applied normal to the surfaces to prevent further penetration of the contact surfaces (cf. Figure 3).

![Figure 3 Forces exerted on the contact surfaces.](image)

The magnitude of the forces depends on the amount of penetration and the properties of the elements at both sides of the contact surface. The MSC/DYNA User- and Theory manual provide more background on the use of contact algorithms (see "References")

The hull of the struck ship will be loaded by the striking ship and deform severely during the collision process. The elements in the numerical model have an elastic-plastic material behaviour with yielding that takes strain-hardening into account. A numerical element will fail after reaching a pre-defined maximum plastic strain (20% in these simulations), which means that the element has broken and that the stresses in the element are put to zero and that it can not take loading after that time.

Material behaviour itself was not a parameter to be studied, but a wide range of material models are available. A typical result of a step 1 calculation (for test 4) is given in Figure 4.
Figure 4 Time history of velocity of the colliding ships.

Water resistance calculation (step 2).
During the collision the struck ship will mainly get a translational motion and a rotation along its longitudinal (roll) axis. The rotation along the vertical- and transverse axis will be very small. For this reason and also because more than 90% of the struck ship has a prismatic cross-section, the water resistance force acting on the struck ship can be obtained by using a two-dimensional cross-section floating in water and computing the motion of this cross-section with the MSC/PISCES computer code. This program uses a two-dimensional explicit finite volume method and has been heavily used in dynamic fluid-structure interaction. The water is modeled in an Eulerian frame of reference, which means that the computational mesh remains fixed in space and time, with the water moving from cell to cell. The cross-section of the struck ship is modeled as a rigid body and will act as a continuously moving wall boundary for the water in the Eulerian mesh. The water then acts as a continuously changing external pressure boundary at the surface of the cross-section.

The MSC/PISCES User- and Theory manual [see "References"] provide more detailed information about the fluid-structure coupling mechanism.

This two-dimensional approach is not a limitation of the current numerical methodology. In case of a 3-dimensional motion of the struck ship through the water, a three-dimensional version of the MSC/PISCES program (MSC/DYTRAN) can be used, but for the 4 collisions under investigation the use of a two-dimensional approach is very cost effective and can be justified as discussed above.

The numerical mesh of the ship and water that has been used in the step 2 calculation is given in Figure 5.
Initially the ship is at rest and floats in the water. The time-dependent collision force of step 1 is then applied to the struck ship. The ship will now move under influence of this force and the resistance of the water. In Figure 5 the two-dimensional motion of the struck ship through the water is visualized.

The water resistance force $F_w$ (per unit length) can be computed from:

$$F_w = m_s \cdot a_s - F_{Cl}$$  \hspace{1cm} (1)

where $m_s$ is the mass of the cross-section, $a_s$ is the acceleration of the cross-section found in the two-dimensional calculation and $F_{Cl}$ is the collision force (per unit length) from step 1 that is applied to the two-dimensional cross-section.

**Final combined fluid-structure calculation (step 3).**

This simulation is the last calculation and yields the final solution of the ship collision problem in which the influence of water is taken into account by a system of springs and dampers (cf. Figure 6).
The water resistance force is modeled by 26 dampers attached to the unstruck side of the struck ship. The characteristic of these dampers is obtained from the horizontal force found in step 2 as a function of velocity of the struck ship. The total force is obtained by multiplying the water resistance force per unit length of step 2 with the length of the ship. This total water resistance force is divided evenly over all 26 dampers, thus all dampers have the same characteristic. This approach neglects the three-dimensional end effects at the bow and stern of the struck ship as mentioned before.

To allow the ship to have roll motion, a system of 26 springs are attached to the bottom of the struck ship. These springs model the static hydrostatic upward forces according to the formulas below:

\[
\begin{align*}
 f_1 &= \frac{\rho g}{6 \cos \phi} \left[ (2h_1 + h_2) B + \frac{h_1^3 - h_2^3}{B \cos^2 \phi} \right] \\
 f_2 &= \frac{\rho g}{6 \cos \phi} \left[ (h_1 + 2h_2) B - \frac{h_1^3 - h_2^3}{B \cos^2 \phi} \right] \\
 \cos \phi &= \sqrt{1 - \frac{(h_1 - h_2)^2}{B^2}} 
\end{align*}
\]

Figure 7 Hydrodynamic forces acting on a section of the ship.
where \( f_1 \) and \( f_2 \) are the forces exerted by the springs on the ship per unit length, \( g \) is the gravitational acceleration, \( \rho \) is the density of the water, \( B \) is the width of the ship, \( h_1 \) and \( h_2 \) are drafts on both sides of the ship and \( \phi \) is the roll-angle.

A typical result for a step 3 calculation is given (again for test 4) in Figure 8. The residual velocity of striking and struck ship immediately after the collision is lower than that obtained in the calculation without water.

![Image](image_url)

**Figure 8** Time history of velocity of the colliding ships and deformed geometry (step 3).

In Figure 9 the energy dissipation during the collision process is depicted.

![Image](image_url)

**Figure 9** Energy dissipation.

In Figure 9 the energy dissipation during the collision process is depicted. The water has now dissipated a considerable amount of energy during the collision and therefore the total amount of energy that has been dissipated during the collision has increased with respect to step 1. This increase in energy dissipation results in a decrease in residual velocity of both ships immediately after the collision. These results show without any doubt that a combined fluid-structure approach in numerical ship collision simulations is necessary. A pure structure-structure interaction, like in car-crash analysis is not sufficient to give accurate results.
The effect of the application of springs at the bottom of the struck- and striking ship in the collision simulation is revealed in Figure 10.

Figure 10 Roll-motion of the struck ship

RESULTS OF THE NUMERICAL SIMULATIONS

Introduction
In this section the results of the four ship collision simulations are presented. These results are a summary of the results presented in a report by Thung and Lenselink (1992). The most important characteristics of the four collision scenario's are given in the table below:

<table>
<thead>
<tr>
<th>Test</th>
<th>Striking ship</th>
<th>Struck Ship</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Velocity (km/h)</td>
<td>Total Mass (kg)</td>
</tr>
<tr>
<td>1</td>
<td>5.3</td>
<td>985140</td>
</tr>
<tr>
<td>2</td>
<td>14.8</td>
<td>985140</td>
</tr>
<tr>
<td>3</td>
<td>15.2</td>
<td>985140</td>
</tr>
<tr>
<td>4</td>
<td>15.6</td>
<td>985140</td>
</tr>
</tbody>
</table>

Table 1. The different collision scenario's

Collision damage
The amount of damage inflicted on the struck ship is given as a series of deformed geometry plots after the collision in Figure 11 to 14. In these figures the numerical elements that have failed on maximum plastic strain are removed and holes in the ships hull can be visualised in this way. Also a top view of the struck ship is given in which the measured deformation at deck level is plotted.

In all the experiments small scale buckling has occurred at the gangway as well as on the trunk deck. The dimension of this buckling is smaller than 0.1 m. In the simulations this buckling behaviour has not been found because the numerical element dimension in those regions was much too coarse to resolve this buckling behaviour and instead a number of failed elements are found at these locations.
test 1
The damage caused by the collision in test 1 is visualised in Figure 11. A dent has been made in the hull of the struck ship but the hull itself did not fail. The final penetration computed at gangway level is .36 m. During the test a crack (about 30 cm long and only a few cm wide) has been found at the strike location.
In the simulation the maximum plastic strain at the inside of the hull has already reached 20 %, but the shell has not yet failed over its full thickness. So, the ships hull in the simulation is starting to fail.
The final deformation in the experiment was in good agreement with the simulation.

Figure 11  Damage after collision test 1 (dimensions are in meter)
test 2
The damage caused by the collision in test 2 is visualised in Figure 12. A large hole has been formed in the hull of the struck ship. This hole runs down from the gangway to the horizontal stringer in the hull. The ships structure has been pushed inward between the two transverse tank bulkheads and the hole is located at the strike location. The final penetration computed at gangway level is 1.15 m. During the test a penetration of 1.02 m was found and the deformation pattern in the simulation is in very good agreement with the test.

Figure 12 Damage after collision test 2 (dimensions are in meter).
test 3
The damage caused by the collision in test 3 is visualised in Figure 13. A large hole has been formed in the hull of the struck ship. This hole runs down from the gangway to just below the horizontal stringer in the hull. The ship's structure has been pushed inward between the two transverse tank bulkheads, but not as far and over a smaller extend than was the case for the unmodified ship in test 2. The final penetration computed at gangway level is 1.0 m. During the test a penetration of 0.77 m was found and the deformation pattern in the simulation in good agreement with the test. In the experiment no hole was found at the strike location, but instead a crack has been found just outside the collision area. The crack was initiated from a weld line in the shear strake just beside the web frame.

Figure 13 Damage after collision test 3 (dimensions are in meter).
The damage caused by the collision in test 4 is visualised in Figure 14. A large hole has been formed in the hull of the struck ship at the strike location. This hole runs down from the gangway to just below the stringer deck. The ship's structure has hardly been pushed inward between the two transverse tank bulkheads. The stringer deck and the tank inner wall are not penetrated and have only undergone a (small) plastic deformation. The final penetration computed at gangway level is 1.0 m. During the test a penetration of 0.92 m has been found and the deformation pattern in the simulation is in excellent agreement with the test.

Figure 14 Damage after collision test 4 (dimensions are in meter).
Collision force

For all the tests the computed maximum collision force is higher than the measured maximum collision force. As a typical example, the computed and measured collision force for the test 4 collision are given in Figure 15.

In the experiments the contact force was determined by force transducers, that were situated just behind the bow. The collision force was measured as the force between the bow and the rest of the striking ship. The deceleration of the bow is not measured in this way and therefore the measurements will differ approximately 5% from the actual collision force.

The collision force in the simulations is computed from the deceleration of the struck ship that behaves as a rigid body. However, in the experiments the striking ship is not a rigid body but can deform (elastic) and absorb collision energy that will be released at the end of the collision process. This effect will lead to an increase in collision time and a decrease of the collision force.

The duration of the collision in the simulations is in good agreement with the experiments.

Ship motion

The transverse motion of the struck and striking ship is resolved quite well in the simulations (c.f. Figure 16). Hardly any roll of the struck ship was found in the test, but in the simulations a much bigger roll-angle was computed when the collision was over (t > 0.6 sec). The characteristics of the dampers are only valid during the collision when the struck ship and water are accelerated and they should not be used to compute the ships motion after the collision.

Figure 15 Collision force history. The collision force history.

Figure 16 Transverse and roll motion of the struck ship.
Conclusions

• In the cases where no crack initiation by a weld-line outside the strike area occurred, the numerical simulations were in very good agreement with the experiments when penetration depth, shape of collision area and hole size are regarded.

• In the case where crack initiation by a weld-line outside the strike area occurred (test 3), the numerical simulation did not resolve the crack because it was not taken into account in the modeling. However, a better match with the experiment can be obtained when at that spot the weld-line would be modeled by a number of numerical elements with a material model with a substantially reduced maximum plastic strain.

• Small scale buckling occurred at the gangway and at the trunk deck during the experiments. The typical dimensions of this buckling behaviour was smaller than 0.1 m. In the simulations this buckling has not been found, because the element dimensions are too big to resolve this behaviour. A very fine zoning would be required to resolve this phenomena and this is only feasible when techniques like "sub-cycling" can be employed.

• The maximum computed collision force is for all collisions higher than the measured maximum collision force.

• The computed collision duration agrees well with the experiments.

• The ship motions after the collision (especially rolling) can not be computed accurately when the system of springs and dampers is used. A better solution will be obtained when the structure-structure interaction can be handled simultaneously with the "full-coupled" fluid-structure interaction, resulting in one computer calculation in which the water resistance is computed exactly. With the MSC/DYTRAN program this approach is now possible.

References


6. Ship Production

6.1 Quality Assurance

6.2 Shipyard Performance

6.3 Shipbuilding Technology

6.4 Information Technology
EUROPORT '93

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Quality assurance in naval shipbuilding
I. Adriaanse

Abstract.

Contracts for the building of Naval ships - and for the greater part of Merchant ships as well - include requirements on Quality Assurance according to the international standards, for instance AQAP-1 or ISO-9001. Elaborating these requirements into an efficient and company-oriented quality system demands a high level of engagement of the company’s employees on all organization levels.
Insufficient engagement on the part of the employees will often lead to a large amount of written manuals, procedures and instructions, experienced by those involved as a non-integrated part of the organization and therefore considered as an extra workload.

For some years Royal Schelde developed and introduced a company information system in which the requirements of AQAP-1 and ISO-9001 have been integrated.
The set-up of the system is process-oriented with "information" as a basic concept.
The system has been laid down in process diagrams and information-instruction-descriptions.
The managers on all organization levels were and are still held responsible for their share of the information records as part of the system as well as for the implementation and observations thereof.
In this way the organization, the procedures and the quality aspects during all the phases of the production process, have been laid down in a clear and compact way, while the production process itself is carried out under controlled conditions.

The goal of this presentation is to present examples of to-day’s practice in relation to the realization and implementation of Quality Assurance in Shipbuilding.
1. INTRODUCTION.

This presentation will also be based upon the experience gained during the early seventies and up till now by extended implementation and maintenance of the quality assurance system for Royal Schelde’s Business Unit Shipbuilding.

Royal Schelde was established at Vlissingen in 1875 under the name of Koninklijke Maatschappij "de Schelde", mainly focusing its attention on shipbuilding and marine engineering.

Under the influence of the industrial revolution its activities expanded to various other branches. Through the years the business has developed into a company which now employs about 3600 people. It yearly sales value amounts to more than NLG 800 million.

In 1992 the organisation started to convert into a more market oriented structure.

The name of the group of companies was changed into "Koninklijke Schelde Groep", however the English version remained the same: Royal Schelde.

The core of the new organisation structure consists of ten business units, each working with a high degree of autonomy.

Maintaining individual responsibility for their results, these business units are covering Royal Schelde’s activities in the field of marine constructions, energy conversion, process and environmental technology, curtain walling, industrial services and the design and development of products composed of exotic metals and/or advanced composites.

A number of central staff departments supports the business units and the Board of Management.

Each Business Unit includes its own quality department. Structural deliberation remains between the head of the central staff department for "Quality Control/Assurance" and the heads of the Business Units quality departments.

A brief summary of Royal Schelde’s organisation is given in figure 1.

---

**Figure - 1 Royal Schelde organisation structure.**
2. **SCHELDE SHIPBUILDING.**

The core business of Schelde Shipbuilding mainly consists of:

**Naval Vessels**
- design and construction of surface naval vessels, including vessels for coast-guard duties and other para-military application.
- service life-extension programmes

**Merchant Vessels**
- design and construction of sophisticated vessels

**High Speed Ferries**
- design and construction of "SES" (Surface Effect Ship)

A summary of secured orders from 1975 up till now, is:

10 Standard Frigates
2 Air Defence Frigates
1 Diver and Hydrographic Training School Vessel
1 Torpedo Recovery Vessel
8 Multi-Purpose Frigates
1 Surface Effect Ship
1 Auxiliary Oiler and Replenishment Ship
1 Ro-Ro Passenger Ferry

3. **QUALITY SYSTEM SHIPBUILDING.**

The contract for building the Standard Frigates implied that during the execution of this contract a quality system had to be applied meeting the requirements of the AQAP-1.

It then was for the first time that Schelde Shipbuilding got a contractual obligation to apply and to perform according a quality system.

The quality system developed and implemented at that time was completely department-oriented and it was laid down in department manuals.

Although that quality system was meeting the requirements of the AQAP-1, an increasing number of disadvantages was met in the course of years when practising and maintaining the system.

Those disadvantages concern among others:
- the large number of written manuals;
- the process-oriented activities had been described in different manuals;
- the same general information was given in each manual;
- the junctions of activities from different departments were badly regulated in many cases;
- the top-down structure was not clearly visible;
- the "quality-loop" aspects had been insufficiently described;
- the responsibilities and competences had been insufficiently described.

For a.o. the above mentioned reasons, the top-management of Royal Schelde decided in 1986 to establish a process-oriented quality system which should be laid down by means of a different methodology.

The basis of this system is the following:

For an effective and efficient functioning of an organization, it is of importance for quite a number of activities to be performed in a regulated and always identical way.

In order to realize such a functioning and because all activities are controlled by means of information, a company information system has been chosen in which:

- company processes (activities) and information flows are shown by diagrams and
- information-instruction descriptions are prepared in which the relative staff employees are mentioned.

The development and subsequent elaboration of this company information system has been executed in accordance with a plan of improvement, prescribed by the Royal Schelde's management.

An important aspect of this matter was the formation of working-teams, consisting of managers and executives / staff-members from the various line-functions. Those teams were responsible to the top-management and were co-ordinated by a control panel. The advantage there-of is, that the executives were directly involved in the development of the system from the very beginning, bringing them the experience the system is an integrated part of the organisation. Moreover, because of that fact the implementation of the system was simplified considerably.

4. THE COMPANY INFORMATION SYSTEM.

General.

The system is process-oriented and contains the following company processes:
- Managing the enterprise.
- Managing primary processes.
- Marketing and sales.
- Managing of projects.
- Development, design and engineering.
- Purchasing goods and services.
- Materials management.
- Production.
- Setting to work, Testing and delivery.
- Servicing the product in the field.
- Providing support.

These company processes are shown in diagrams by means of the IDEF-0 methodology and focusing on the "information flow".

(IDEF = Integrated DEfinition Function modeling method). This means that in the diagrams function boxes are shown which are connected by information channels. A box, together with its input and output arrows can be considered as an element of the diagram.

A general impression of such a function-box is shown in figure 2.

![Diagram](image)

**Figure 2 Typical IDEF-O element.**

The function (process/activity) transforms input into output. However, this process of transformation is subjected to controls, which keep the transformation between certain limits.
Mechanisms as human resources (professional skill and experience) and means (technology, buildings, equipment, tools etc.), which help to bring about a function but which are not changed as a result of the activity, are necessary.

Finally, a different function can be called from the function in the box concerned through call. A call is an arrow pointing downwards in a diagram which refers to a process specified elsewhere and as such brings that process into the diagram. Near the "call"-arrow the number of the diagram is given which provides further information about the function called.

**Diagram structure.**

The first box of a complete set of diagrams represents the system one wishes to show. This box is only shown in the top diagram, the so-called A-O (A minus zero) diagram. In the next more specified diagram the structure of the functions within the system is shown, resulting in the AO (A zero) diagram. So the AO diagram is created by zooming in on the A-O diagram.

By zooming in on the functions of the AO diagram, a new diagram can develop from every box. In this way a top-down hierarchy of the diagrams is formed, the first ones representing the structure of the total and the last ones the structure of the specified activities.

Such a structure is shown in figure 3:

![Diagram](image)

Figure 2 Typical IDEF-O structure.
This composition clearly shows that the diagram numbers represent the relations between the functions. Each time when a figure is added one arrives at a lower composition level. This is a so called the parent/child relation. In case of two consecutive diagrams, the highest diagram is regarded as the parent of the lowest diagram.

The diagrams are linked together by the numbers! With the help of these numbers an index can be made of all diagram boxes, the so called "node-index". The "A" before the numbers means "Activity".

**Arrows.**

In this method it is possible to find back the arrows crossing the boundaries of the scheme in the child-diagram in the parent-diagram on the box originating the child-diagram. As shown in the A12 diagram in the previous figure, for example, four arrows pass the lines of the scheme and four arrows are connected to box 2 of diagram A1.

The arrows can be regarded as channels along which the information flows. In the direction from left to right, they indicate feedforward flows. Arrows going from right to left are considered feedback flows.

Status reports (indicated in the diagrams as status) and problem definitions (indicated in the diagrams as problems) represent important feedback information. Such feedback information is shown in nearly every diagram.

As explained before, the arrows in the diagrams shall serve as information channels. These information channels operate by means of several kinds of "data carriers", like reports, drawings, computer printouts, monitor information, even verbal information, etc.

In order to obtain an overview of all the information playing a role in the diagram structure, an information-instruction description is made for each carrier or group of carriers together.
Information-instruction descriptions.

In the information-instruction descriptions all important documents and all duties and responsibilities of the involved executives are laid down. The information-instruction descriptions are laid down in a standard form consisting of two parts. In the first part the function, contents and use of the data carrier is given together with possible references to connected procedures and/or instructions. In the second part those who are responsible for the preparation, review and authorization of the carrier are mentioned as well as those who have to take actions as a result of the contents of the carrier. This second part of information-instruction descriptions combine the company’s organization with its structure of functions.

An example of such an information-instruction description is given on page 10, figure 6 and page 11, figure 7.

Documentation of the company information system.

These documentation comprises the following:

- ROYAL SCHELDE MANUAL, containing:
  - the organization of Royal Schelde;
  - diagrams (functions, processes-activities);
  - information-instruction descriptions;
  - general information, such as the explanation of the system and control-aspects.

- BUSINESS UNIT MANUAL, containing:
  - the organization of the business unit and the business unit’s departments;
  - duties, responsibilities and competences of the managing employees.

- PROCEDURES, in which a coherent description is given of the working-method within a certain process as a further specification of the diagrams and information-instruction descriptions.

- INSTRUCTIONS, that (only if necessary) are prepared by the department’s management, and which also control the distribution and performance.

The advantages connected to the above mentioned company information system are among others:
- based on the flows of information in the company processes, the usual working-methods have been fixed;
- the requirements of ISO-9001 and AQAP-1 have been integrated in these working-methods;
- the system contains a minimum of documents and it provides a clear insight into its structure (top-down);
- the necessary data carriers as well as the involved duties and competences have been laid down in a uniform way;
- the principles of the "quality loop" have been completely integrated into the system.

![Quality Loop Diagram](image)

Figure 4 Quality Loop.

5. ORDER-ORIENTED APPLICATION OF THE COMPANY INFORMATION SYSTEM.

For the execution of each contract a project-manager is appointed by the director of the business unit. Since the company information system describes all company’s processes and where at the same time all requirements of both the ISO-9001 and AQAP-1 are integrated into those processes, it is necessary to determine for each project which parts of the system are applicable.

This is to be based on the Royal Schelde’s policy as well as on the contract-requirements.

The above will be triggered by process A213-1 "manage projects", as shown in figure 5.
This diagram shows the data carrier: "Project plan" as one of the outputs from the constituent process A213-11 "Make project plan".

To this data carrier is connected the information-instruction description A213-1/A-"Project plan" as shown in figure 6.

Figure 6 "Project Plan".

* This means a statement of applicable parts of the company information system in relation to the order concerned, and is based on:
  - company's policy
  - contract requirements
According to the above shown information-instruction description, the specific project organisation and the control aspects for quality, progress and costs will be laid down in the project plan.

An information-instruction carrier that must be prepared for each order, is the "Inspection plan". This carrier is initiated in the process: "Production" and it is an output of the constituent process: "Manage production".

The description of this carrier is contained in the information-instruction description A213.51/A - Inspection plan as shown in figure 7.

As can be concluded from this description, the inspection plan is of essential importance to initiate and schedule necessary inspection activities, registrations as well as the involvements of both the quality department and the client before starting the production.

Figure 7 "Inspection Plan".
As mentioned before, the principles of the "quality loop" have been completely integrated in the company information system. With the assistance of registrations, analyses and reports of status and problems it will be determined whether and in which way measurements for improvements shall be taken. This information can also be used by project-teams or quality-circles in case a further investigation appears to be necessary according to Royal Schelde Continuous Improvement.

6. CERTIFICATION OF THE COMPANY INFORMATION SYSTEM.

Royal Schelde's company information system (used as the quality system documentation) has been certificated in April 1990 by the Dutch Ministry of Defence and it meets the NATO quality assurance requirements specified in STANAG 4108, AQAP-1/edit.3. The certificate was valid till May 1st, 1992 and is being renewed.

However, company evaluations for the certification of quality systems will no longer be carried out by the Ministry of Defence.

For that reason Royal Schelde demanded the services of Det norske Veritas, who started to evaluate the present company information system in comparison with the requirements of ISO-9001 and AQAP-1, in order to issue a certificate.

The Business Unit Schelde Boilers was, based on the same company information system, certificated in October 1991 by Det norske Veritas. The system met the requirements of ISO-9001.

7. FINALLY.

One remark has to be made:
People have to work with the means described in this paper.
Having a quality system or a certificate does not assure quality, people have to do so by their continuous attention and the system is just a helpful tool.
The influence of project management on quality
J. Skirving, H. de Wit

Abstract:

Quality is defined as more than just meeting a product specification and is seen as conforming to the customers requirements and expectations. Achieving the required quality is not the task of only the production workers but depends on actions taken by the whole organization, including the top management.

The role of the project manager and his influence on final quality is explained. A 22 m. tug being built under licence in South America is used as an example of how the actions of various departments can have an influence on the quality of the final product.

What is quality?

Until fairly recently quality was often seen as something superficial such as a nice paint job, smooth finish or correct tolerances.

During the past two decades the concept of a quality product or service has changed from that of just meeting a product specification to a much wider area including:

- Conformance to customer requirement and expectation;
- Prevention and improvement instead of inspection and re-work;
- Recognition that management and not the work force is responsible for "poor quality".

Quality is no longer looked on as a luxury or as belonging to an article that has a high price card. A Lada can be as much a quality product as a Mercedes, the main criteria is that it meets the customers requirements or expectations.

A customer who buys a 30 HP Lada will not expect the same performance as from a 150 HP Mercedes, but would, rightly, be angry if the car failed to start or repairs were needed just after purchase.

The quality of the finished product is not determined by the people who build it or assemble it but is the result of actions taken at all levels within the organization.

A salesman who gives a too optimistic delivery date is as guilty of poor quality as the designer who specifies a performance that cannot be achieved and the bookkeeper who irritates suppliers by not paying invoices in time.

A ship which is delivered too late does not conform to the customers requirements and expectations and therefore is not to the necessary quality - even if the technical performance such as speed and bollard pull meet the specifications.
Project management at Damen Shipyards

If we accept the statement made earlier that "quality is conformance to customer requirements" it is obvious that project management will have a great deal of influence on quality. At Damen Shipyards all projects can be split into two phases. During the first phase the product group, that has specialized in the particular type of ship being offered, would translate the customer requirements into a building specification and general arrangement drawing and make a cost price estimation and delivery schedule. Depending on the type of ship - standard, based on a standard or custom built - they would also make a preliminary design in order to check stability, steel weight, performance, etc. If necessary they will call on the expertise of the Damen Research Department or outside experts such as a technical university to check on some specific technical requirements such as behaviour under certain weather conditions, etc. This stage will obviously have a large influence on the final quality.

The second phase - and the one dealt with in this paper - is after a contract has been signed. At this point a project manager would be selected from a pool of experienced production co-ordinators. The choice of the project manager will depend on a number of factors including the type of ship, the type of customer and the building location, for example the main shipyard, one of the sister companies in the north of Holland, a sub-contractor or even, in the case of licensing, at a shipyard on the other side of the world. Experience has shown that the choice of the right project manager is probably the single most important factor in the success of any particular project, by definition he has a great deal of influence on customer satisfaction and therefore the quality of the end product.

Some project managers may be very good at working with bureaucratic organizations where everything has to be done by the rule book and the company has had many years of experience in purchasing of new ships. The same project manager could be totally unsuited for a contract involving a captain/owner who has never purchased a brand new ship before.

At Damen Shipyards the project manager is the hub around which all the activities needed to design, construct and deliver the ship revolve. This is shown in figure 1, for simplicity, sub functions such as logistics who report to the purchasing department and the research department who work for the drawing office are not shown. The first action that the project manager takes is to call a meeting of his project team. This team would consist of the project buyer, the drawing office group leader and a representative from the work planning department. During the first meeting of the project team (which could take a whole day) the salesman who signed the contract and the product manager who was responsible for the first stage of the project would give background information such as who the customer is, his marine experience, number and type of ships in his present fleet, etc. They would also give the technical background to the project, why a certain design or arrangement was chosen, which data has been carefully checked and which is only preliminary, etc.
Each member of the project team will prepare a milestone planning for his group's activities. These will be bundled by the project manager into an overall planning and checked against the contractual delivery schedule. Any shortfalls would be removed by re-allocating the available time or by increasing capacity of activities on the critical path.

The various activities of the members of the project team will now be looked at, using an order for the construction at a shipyard in South America of two 22 m. Damen Stan Tugs as an example. These ships are an almost identical repeat of two tugs which had been built in The Netherlands and delivered to the same customer 20 years ago. Although these tugs may look a little bit dated - and are in fact no longer part of our standard range - the customer insisted on repeats and did not want a more modern design.

Design and construction drawings

The amount of drawings required for a new building will depend very strongly on the type of vessel involved and the degree of standardization. For the 1600 b.h.p. Stan Tug shown below in figure 2 - one of the standard ranges - only 500 drawing office hours would be required, a new custom built design could need upwards of 10,000 hours. The project manager specifies what has to be drawn and to what detail. His starting point will of course be the requirements of the classification society plan approval office.
The final amount of drawing work will depend on the building location, this could be at one of the groups' shipyards that specialized in that type of vessel - in which case a minimum of new drawings would be needed - or at a shipyard that had little or no experience. A typical case of the latter is when a ship is being constructed under licence; experience has shown that 20-30% more drawings would be necessary.

One of the main tasks of the project manager is to ensure that sufficient drawings - of the correct quality - are made available to the production departments. This is one area where the use of standardized components that have been well designed, already in use in a number of ships and are therefore free from teething troubles, can have a large influence on the quality of the final product.

Figure 2 Damen Stan Tug 4

Purchasing specifications

It may seem a rather obvious statement but you only get what you specify. This means that the purchase specifications have to be detailed and leave no room for misunderstanding. A basic data sheet is prepared for every newbuilding order and forms an integral part of the purchase specifications. A typical data sheet would include details of the required classification notation, climatic conditions in the country of operation - humidity range, maximum and minimum temperatures - the language to be used on nameplates and instruction manuals, etc. as well as any specific requirements. These would be determined by the project manager and would depend on the method of construction and location of the building yard.
The engines of a ship being built under licence in, say, Sudan could be stored on site in sandy, windy conditions for months before the engines were installed and commissioned; in this case special attention would have to be paid to painting, conservation and packing.

Work preparation department

The use of standard components and modules, even in custom built designs, has made it worthwhile investing in an integrated work preparation system linked via workstations to the drawing office and a data bank that contains details of all standard components. These components are stored in a file server in the form of a three dimensional model complete with the type of information such as material, part number, specifications, etc. that would normally be shown on the parts list attached to the working drawing.

The parts list is generated and filled by the draughtsman at his workstation and forms the input to the work preparation department where the planner can access it through a P.C. The work planner uses the parts list and drawings to prepare a job book that specifies every single "job" that has to be carried out on board. The job book forms the basis of the construction manual and packing list and could have upwards of 100 pages. It will give details of the specific job, the drawings required, the necessary material and equipment and, in the case of a ship being built abroad, the location of each item in the containers used for shipment.

It is the task of the project manager to ensure that the information generated by the work planner is sufficient enough to allow the job to be done. The level of detail required will depend to a large extent on the building location. Forgetting a number of bolts can be annoying when a ship is being built at a shipyard with a well stocked store and access to suppliers; it could be a major problem if the ship was being built under licence at a shipyard in a country that does not have a good infrastructure.

Sub-contractors

The project manager has the right to veto the use of a particular sub-contractor if he feels that they will not give him the required quality. This veto right is very seldom used but is important as it emphasizes that the project manager is ultimately responsible for the final product and cannot hide behind statements like "I wanted to use company X but was forced by the Purchasing Department to use company Y".

Many of the sub-contractors used by Damen Shipyards have facilities in the yard and have a long experience of co-makership. This gives the sub-contractors a certain degree of continuity of work and reduces the dangers - often associated with the use of contractors - that they only look at the profit on the current job and do not look to future work.
Giving the project manager the veto right helps to keep subcontractors on their toes and prevents them from taking a short term view. The open management culture at Damen Shipyards means that if a project manager is not satisfied with a contractor, his colleagues will soon know this, and just as important, know why he is not happy about using a particular contractor or supplier.

Guarantee claims

The project manager is expected, all other things being equal, to deliver his ship within the estimated cost price. This does not mean that he can start to cut corners if the ship threatens to run over budget. One of the items in the standard cost price estimation is an allowance for guarantee work. The size of this allowance depends on the type of ship, the number already built and feedback from users and our own service engineers.

During the guarantee period, which would normally be one year after delivery but could be longer, all claims, costs and expenses, etc. will be booked to the building number - even if the total of all the costs is higher than the pre-calculated allowance. This method ensures that the project manager will not save costs by using lower quality materials or accepting known defects before delivery. The cost of replacing a faulty component or fixing a defect on a ship operating on the other side of the world will always be higher than doing the job correctly in the first place. In the event of major problems with guarantees the project manager is expected to resolve them to the mutual satisfaction of both the yard and the customer. This could mean spending weeks at a repair yard in Africa or the Far East co-ordinating the repair or modifications. Quality does not cost money, it saves money by cutting out rework and repairs.

Summary

The project manager is ultimately responsible for the quality of the product or service and is given sufficient freedom of operation to enable him to carry out this task. He is the hub around which the production organization is built and he steers the various departments towards their ultimate goal - not that of producing drawings, buying material or installing an engine - but keeping the customer satisfied; at the end of the day this is what quality is all about.
Abstract

Complying to stringent naval shipbuilding standard demands a comprehensive quality assurance system which the shipyard lacked in the early years. As more ship types were designed and constructed, this deficiency manifested and has brought negative impact on reputation to the shipyard. To ensure compliance with quality standard, cut warranty costs and to protect long term business strategy, the shipyard embarked on an aggressive drive to promote quality achievement. From an inspection-oriented type of simple quality control, the shipyard developed and implemented an effective system coined by the shipyard as Company-Wide Quality Assurance (CWQA), which encompassed the involvement of all departments towards quality achievement. The capability of building desired quality ships and satisfying customers' specifications was due to the success in making quality attainment accepted as every employee's responsibility, and the more organised and systematic documentation of quality matters. Outside the shipyard, vendors and contractors were required to comply with the shipyard's quality requirements before their sales or services were contracted. The shipyard's CWQA has been adopted by a few companies to which the shipyard was then a consultant. This paper presents the overview of the shipyard's quality assurance activities in which development the author was the lead contributor.

Introduction

The shipyard has established a long history and experience in naval shipbuilding. Complimented by the lack of fierce competition in the early years, the business of the shipyard was good, despite the absence of a comprehensive quality assurance system, which recently, is almost a mandatory requirement especially in the manufacturing industry. The shipyard survived because it was not a norm to require shipyards to operate in accordance with a quality standard, such as what is a household name today, the ISO 9000 series.
or the BS 5750 series. The lack of a quality system did raise customers’ dissatisfaction which very often could adequately be compensated by re-work without costs and providing more spare parts, and sometimes by extending the warranty period. This did not mean that the shipyard was not concerned about the expenditure in fault-finding to discover malfunctioning, design change brought about by bad quality and warranty.

As more ship types were designed and constructed, the lack of a quality system manifested itself in rising failure costs and receipt of more customers’ complaints. To safeguard its reputation which was declining and to fight the ever increasing competition in the later years, the shipyard was compelled to re-examine its shipbuilding activities. In this endeavour, the shipyard discovered the many factors contributed to poor quality. It believed that the solution was to make strategic changes. This marked the beginning of company-wide quality assurance for the shipyard.

Company-wide quality assurance

Having suffered much from failure costs and lost of reputation, the shipyard admitted the significance of quality in shipbuilding. It adopted the philosophy that quality was the responsibility of every employee who must contribute towards quality achievement. Based on this slogan, the shipyard embarked on a quality drive in an attempt to make quality an integral part of every employee’s work. For organisational convenience, the responsibility for quality management was assigned to the quality assurance (QA) department. Soon after top management has established the company policy, the race towards company-wide quality assurance (CWQA) began. It was the shipyard’s firm belief that CWQA was the tool to re-gain and sustain customers’ confidence, and to remain competitively strong in naval shipbuilding.

Quality assurance department as the managing agent for CWQA

Before CWQA implementation, the level of quality as defined by the shipyard was that to be achieved by inspection by the QA department. The principal role of the QA department then was inspection to verify that construction and installations conformed to the requirements of pre-declared acceptance documents such as the ship specification.
After the QA department has been assigned the additional responsibility for quality management, it carried out its duties more than just inspections. Being the spokesman on CWQA matters, it co-ordinated the company-wide quality development activities, while at the same time, like in all other divisions, has to re-shaped its internal organisational structure so that it was oriented towards CWQA. To fulfil the multiple roles, the immediate requirement for the QA department was the teaming of quality personnel. This was done by recruitment and engagement of a quality consultant. Where specialised knowledge was required and not justifiable to employ a permanent staff, expertise from other divisions was incorporated to the QA department. With the total knowledge required satisfied as shown in Fig. 1, the QA department was transformed from an inspection department to a department performing the advisory role on CWQA, the challenge the QA department has overcome.

<table>
<thead>
<tr>
<th>Quality Assurance Department for CWQA</th>
<th>Other Divisions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Knowledge</strong></td>
<td>Supporting Knowledge/ Input</td>
</tr>
<tr>
<td><strong>Basic</strong></td>
<td><strong>Others</strong></td>
</tr>
<tr>
<td><strong>Inspection</strong></td>
<td>Marine/Mechanical engineering</td>
</tr>
<tr>
<td><strong>Testing</strong></td>
<td>Shipbuilding</td>
</tr>
<tr>
<td><strong>Trial</strong></td>
<td>Electrical engineering</td>
</tr>
<tr>
<td><strong>Other trades</strong></td>
<td>Quality engineering</td>
</tr>
<tr>
<td>- Welding</td>
<td>Quality administration</td>
</tr>
<tr>
<td>- Painting</td>
<td>Quality development</td>
</tr>
<tr>
<td>- Corrosion</td>
<td>Weapon systems</td>
</tr>
<tr>
<td>- Woodworking</td>
<td>Electronics</td>
</tr>
<tr>
<td>- Metrology</td>
<td>Control engineering</td>
</tr>
<tr>
<td>- Instrumentation</td>
<td>Input from equipment suppliers</td>
</tr>
</tbody>
</table>

Fig. 1 - Knowledge requirement of QA department for CWQA

The activities for CWQA development of the QA department became interactive. Although not solely responsible for CWQA, it however, oversaw and co-ordinated the company-wide development. In this centralised role, the QA department, supported by divisional quality representatives, provided
assistance to help implementing, maintaining and reviewing quality systems. To fulfil this respect, the QA department was always involved in all phases from marketing to after sales. The crossover of the quality assurance activities into other disciplines is shown in Fig. 2.

Fig. 2 - Quality assurance activity loop

Quality organisation

All divisional directors reported to the managing director on all matters pertaining to quality policies. The directors were required to state their divisional quality policies and establish the quality objectives, and were responsible for instituting an internal quality system to ensure that policies were carried out and the objectives achieved.
For the reason that the technical division was first identified to require a quality system, it was considered most appropriate to organise the QA department within the technical division which housed the design departments and drawing offices. All paper work for specifications, purchasing, production, testing and trials were generated from the technical division. Being under the same roof, the QA department has immediate contact with the technical personnel to ensure that all quality commitments were discharged so that the paper work, based on which procurement and production were planned and executed, was in order before issuing. Although the QA manager reported to the technical director, the former carried out his duties and responsibilities independently of the technical activities. This was possible as the director’s quality role was well defined and he has to place his priority right. In fact, as the shipyard has discovered, it was effective to implement and resolve quality matters in the technical division with the director entrusted with the responsibility for quality commitment. The notable changes in the division were the requirement for design review, systematic vetting of production drawings and incorporation of quality parameters in drawings and contractual documents.

The implementation of a quality system in the technical division was seen as the first success in CWQA. Based on the experience gained from the technical division, each director was assigned the additional role for quality management in his division.

CWQA development

The success in implementing a quality system in the technical division boosted the shipyard’s confidence in continuing CWQA development in other divisions. The implementation in the technical division was used as a model. Some of the eventual quality activities implemented in other divisions were:

Production - Production review to ensure quality achievement
Project management to include quality activities
Quality control planning and management

Commercial - Vendor assessment and rating
Enforcement of quality compliance on vendors
Contract review
Personnel - Quality induction and refresher courses
   Liaison with union to seek supports for quality
   Paid time off to participate quality functions

Finance - Quality cost analysis
   Payment procedure to ensure quality services
   Financial categorisation of vendors' capability
to supply

It was for about four years and not without much difficulty
that CWQA finally became a reality in the shipyard. What
the shipyard has learned about the success in CWQA
implementation was the creation of an atmosphere of quality
awareness and commitment of all employees, and not
authoritatively assigning quality responsibility to every
employee which would only be short lived. The overall progress
from the initial production quality control to CWQA is
illustrated in Fig. 3. The system that the shipyard has
developed is summarised in Fig. 4.

![Diagram](attachment:image_url)

Fig. 3 - Progress from production quality control to CWQA

Documentation for CWQA

As a permanent reference for CWQA implementation and
maintenance, a quality manual was produced for use by all
employees. It described the company policy, organisation
and management system for quality attainment, functions and
responsibilities of each divisions for quality commitment.
The quality manual was a very essential document to customers.
Although it was usually not a contractual document, it has
certainly given customers the assurance of a systematic quality management and the confidence to receive a quality ship.

Complementally to the quality manual, procedures for procurement, production, quality control and other quality related operations were written for systematic execution. In-house quality standards were established for verification of workmanship and conformance to pre-declared acceptance documents. Being the shipyard's managing agent for CWQA, many of the documents were produced by the QA department in consultation with all concerned departments.

Quality assurance documents

Amongst the many documents implemented, the following were the most essential ones:

(a) Company quality standards
(b) Manufacturing procedures
(c) Technical information sheets
(d) Inspection check lists

Company quality standards (CQS) were in-house standards developed based on experience and adaptation from military and other shipbuilding standards. They were purposefully used to ensure that compliance of workmanship and other quality parameters with acceptance documents has reached the minimum level as stipulated in the standards.

Manufacturing procedures (MP) described how a task should be systematically executed. As shipbuilding processes are multi-disciplinary trades, the implementation of manufacturing procedures has proven to be very productive. The specific benefits of their use were as follows:

(i) Pre-requisites for a task could be identified for advanced preparation of resources, and liaison to resolve potential problems to avoid causing delay in starting.

(ii) Work sequence for a task could be defined so that little pre-planning and minimum supervision would be required during operation.

(iii) Quality requirements could be specified so that an inspection plan could be incorporated.
(iv) Interaction with owner's representative and classification surveyors could be established in advances for the purpose of inspection and acceptance in order to avoid unnecessary interruption to the progress of production.

Manufacturing procedures have been particularly useful for new processes, critical installations and multi-disciplinary tasks. To protect confidentiality some procedures such as those used for weapon systems installations were restricted to designated users only. Manufacturing procedures were standard documents applicable to many ship types. Where additional or different quality parameters were imposed, they were reflected in technical information sheets which served as addenda to the affected manufacturing procedures. This has saved the need to write new manufacturing procedures and to have them approved procedurally each time there was a difference in quality requirements.

Inspection check lists (ICL) enumerated the quality parameters to be verified in sequence. This has ensured systematic and complete inspection. Inspection check lists were important documents as they were permanent records of evidence of quality attainment. Inspection check lists were used throughout the shipbuilding operation for inspections, testing and trials as stipulated in inspection plans.

Quality planning

Soon after the award of a contract and prior to commencement of fabrication, quality planning was one of the major quality activities. The planning activities not limited to the following involved:

(i) Review of inspection facilities
(ii) Certification of process, welders and vendors
(iii) Identification of quality parameters and processes to be inspected or verified, and formulation of an inspection plan
(iv) Identification of inspection system requirements
(v) Formulation of test and trial procedures for contractual acceptance
Quality plan which was another important quality documents gave customers the overview of the shipyards quality system and hence the level of quality attainment.

**Inspection plan**

Inspection plans detailed the job sequence, specified where and what inspections was to be carried out to verify quality compliance and the documents to be used for records and as the appropriate manufacturing procedure. The inspection plan written for the installation of main engine and gearbox is shown in Fig. 5. As could be seen, its usefulness is obviously apparent.

**Inspection system**

The system concerned the planned inspections and did not include other inspections such as random inspections.

(i) In-coming inspection  
(ii) In-process inspection  
(iii) Shop/harbour testing or trial  
(iv) Sea trial

The need for an inspection system is summarised in Fig. 6. The system defined the objective, responsibility, method, documentation, level and class, and treatment of non-conformance. A typical inspection system for in-coming and in-process inspections is shown in Fig. 7.

**Conclusion**

The shipyard has developed a quality assurance system which required the involvement and contribution of all employees. The implementation of the system was successful as every departments accepted the responsibility for quality. Since then, production quality control was displaced and quality assurance activities became company-wide. Comprehensive documentation was used for systematic execution of shipbuilding operations and recording of quality matters. In two of its technology-transfer projects, the agreement to help set up the shipyard’s quality assurance system in two companies was a specific partial requirement of the contracts.
Fig. 4 - Company-wide quality assurance system
### INSPECTION PLAN FOR THE INSTALLATION OF MAIN ENGINE AND GEARBOX

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Operations to be carried out</th>
<th>Documents to be used</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Weigh main engine and gearbox</td>
<td>Weighs to be recorded in Form WE/2 and submit to Design Department.</td>
</tr>
<tr>
<td>05</td>
<td>Establish shaft lines</td>
<td>Ref. d.r.g. no. 5/1 sht 1 &amp; 2/6 sht 1.</td>
</tr>
<tr>
<td>10</td>
<td>Align shaft alignment supports</td>
<td>Ref. d.r.g. no. 5/6 sht 1.</td>
</tr>
<tr>
<td>15</td>
<td>Dimensional check on main engine and gearbox seatings</td>
<td>Ref. MP2-07 and use ICL 035.</td>
</tr>
<tr>
<td>20</td>
<td>Shafting alignment</td>
<td>Ref. MP3-05A and use ICL 074.</td>
</tr>
<tr>
<td>25</td>
<td>Check acceptance of shafting alignment by measuring the radial tolerance and skewness</td>
<td>Ref. document CQS 17/79 Part 1 and use ICL 076.</td>
</tr>
<tr>
<td>30</td>
<td>Install propeller shaft correct to shafting arrangement drawing</td>
<td>Ref. d.r.g. no. 5/1 sht 1.</td>
</tr>
<tr>
<td>35</td>
<td>Main engine and gearbox loading</td>
<td>Use ICL 08/02.</td>
</tr>
<tr>
<td>40</td>
<td>Completion of hull and underwater fittings</td>
<td>Check water tightness</td>
</tr>
<tr>
<td>45</td>
<td>Launching</td>
<td>Ref. gearbox manufacturer's alignment procedure andlor MP3-08.</td>
</tr>
<tr>
<td>50</td>
<td>Align gearbox to shaft coupling</td>
<td>Where tolerances are not specified CQS 17/79 Part 2 is applicable.</td>
</tr>
<tr>
<td>55</td>
<td>Check acceptance of alignment by measuring the eccentricity and breakage simultaneously using two dial gauges</td>
<td>Ref. d.r.g. no. 5/5 sht 1.</td>
</tr>
<tr>
<td>60</td>
<td>Drill and ream holes on seating in conjunction with gearbox (or main engine) mounting feet for holding down bolts</td>
<td>Ref. d.r.g. no. 5/5 sht 1.</td>
</tr>
<tr>
<td>65</td>
<td>Fit holding down bolts. Where fitted bolts are present, fitting force is to be verified and alignment readings to be rechecked for possible runout after fitting</td>
<td>Ref manufacturer's Technical Bulletin No. 654.</td>
</tr>
<tr>
<td>70</td>
<td>Prepare and pour chockfast compound as per manufacturer's Technical Bulletin No. 654.</td>
<td>Technical data given by PRC as follows:</td>
</tr>
<tr>
<td>75</td>
<td>Submit test pieces of chockfast from the same pour for hardness and crushing tests</td>
<td>Crushing 13.3 kg/mm², Hardness 35-40 Barcal.</td>
</tr>
<tr>
<td>80</td>
<td>Release jacking bolts and alignment gear after curing</td>
<td>Minimum curing time at ambient temperature is 18 hours.</td>
</tr>
<tr>
<td>85</td>
<td>Tighten holding down bolts to the respective torque</td>
<td>Ref. manufacturer's Technical Bulletin No. 652A and use ICL 075.</td>
</tr>
<tr>
<td>90</td>
<td>Recheck alignment readings for possible runout</td>
<td>Use ICL 075.</td>
</tr>
<tr>
<td>95</td>
<td>Couple gearbox output flange to shaft coupling</td>
<td>Nominal torque should be 30-40 kg-m</td>
</tr>
<tr>
<td>100</td>
<td>Turn shaft assembly manually to check if it rotates with minimum torque applied</td>
<td>Verification of alignment tolerances by engine manufacturer for warranty purposes</td>
</tr>
<tr>
<td>105</td>
<td>Align main engine to gearbox</td>
<td>Certification of alignment by inspection party</td>
</tr>
<tr>
<td>110</td>
<td>Perform steps 55 to 90</td>
<td></td>
</tr>
<tr>
<td>115</td>
<td>Fit Flexible coupling between main engine and gearbox</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>Couple flexible coupling to main engine and gearbox</td>
<td></td>
</tr>
<tr>
<td>125</td>
<td>Installation complete</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 5 - Inspection plan for the installation of main engine and gearbox**
To ensure that customers are delivered with the ship that perform to the declared specifications

To evaluate performance of existing labour, machines and quality control system

To compare actual quality level with designed level for quality evaluation

To minimise waste and scraps

To determine optimum level for available machines and processes

To check consistency of manufactured quality

To ensure that defective items are not used

To permit work to proceed to the next stage

To ensure that machines and systems perform as designed

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**In-coming inspection**
- Inspection of purchased items:
  - Steel plates and sections
  - Machinery
  - Equipment
  - Sub-contracted parts

Inspections and shop testings in accordance with purchase order specification and drawings

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**In-process Inspection**
- Inspection of work in progress
- Inspection of semi-finished work before passing on to the next stage or trade

Inspection using inspection check lists

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**Final inspection**
- Harbour acceptance trial
- Sea acceptance trial

Trial in accordance with trial specifications and other acceptance documents

Fig. 6 - Inspection system

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Fig. 7 - Inspection system for in-coming and in-process inspections
ABSTRACT

In recent years growing industrialization and trade have been matched by increasing awareness and demands for product quality and safety, better and safer working conditions and protection of the environment. At the present time there is also general agreement that enterprises within industry and trade must demonstrate ability to meet all statutory and other requirements on these matters. The earlier introduction of quality systems and quality standards (ISO-9000 series) has set an example for organizational and other measures by which enterprises seek to manage and control own activities with regard to external and internal requirements, the so-called care management systems. In this paper an integrated approach to the development of care systems for quality, working environment and environmental protection is presented, along with an innovative supporting documentation system and a computer aided tool.

1. INTRODUCTION

In the past years industry and trade have been facing increasing expectations and demands from markets and society with regard to product or service quality, safety of human life and preservation of the environment.

This development can be seen in relation with increasing public awareness about the risks associated with the intensification of the exploitation and processing of natural resources and of industrialization and trade. This has resulted in a number of initiatives for new national and international legislation.

While new proposals are being debated, processed through parliaments and legal procedures or already adopted and implemented, there is an increasing agreement that the primary responsibility for quality, safe working conditions and preservation of the environment lies at the "source". In this respect, enterprises from industry and trade are expected to demonstrate their ability to satisfy market needs and their commitment to social and legislative requirements.

2. FROM PRODUCT QUALITY TO INTEGRATED CARE

Quality can be defined as the capacity of an enterprise to comply with internal and external requirements regarding the control and assurance of product and service quality at the lowest possible costs. External requirements can originate from principals, statutory bodies and authorities.
The traditional way to ascertain compliance with requirements was based on supervision, inspection and control by own personnel, on behalf of principals and authorities. This practice has been gradually replaced by an ordered set of management measures which aim to obtain control of organizational and technical processes, to effective handling of nonconformities, to avoid repetition of errors and to strive for continuous improvements.

An important development in this respect was initiated by the introduction of quality assurance standards which finally evolved into the ISO-9000 series. When the above mentioned measures are set up according to these standards and qualified or certified by accredited bodies, sufficient confidence will be established with regard to organizations' ability to comply with contractual and statutory requirements.

A similar development can already be observed with regard to the care for (human) working environment and environmental preservation. A particular problem here is that legislation requirements are not presented in a form which allows direct "conversion" into easily to be taken measures. A reference model is not available and for this reason attempts have been made to use the ISO-standard as a basis for developing and implementing systems to assure safety, health, environment preservation, etc.

In principle all care systems aim to obtain control of processes, to handle nonconformities, etc., each one being directed at a particular area of interest; it stands to reason that an integrated approach should be followed.

The question is whether legislation can be treated in such a way that "conversion" into an ordered set of measures can be included or integrated within a general care system, while preserving the possibility to highlight specific aspects related to specific requirements.

This matter has been addressed within the frame of the "Shipyard Development Programme", a collective R&D effort initiated and carried out by the Netherlands Shipbuilding Industry Association VNSI. While the shipbuilding industry did not belong to the van of enterprises adopting quality measures and implementing quality systems, shipyards were confronted from the very beginning with legislation on working environment and preservation of the environment.

Most technical processes in shipbuilding and shiprepair produce waste material and emissions which pollute the environment (air, water, ground); this is especially the case with surface cleaning, blasting and conservation.
The above relate directly with the working environment in workshops and on board. Shipbuilding and shiprepair are labour intensive and combine significant physical effort with work in confined spaces and emission of smoke, gases, dust and spray.

The restructuring of the Netherlands Shipbuilding Industry in the seventies and eighties has not only diminished the labour force but has also raised its average age. For to attract young and well trained employees, the industry had to compete against other industries with greater appeal. Improvement of working conditions was necessary as well as the development of an approach which will help safeguard the improvements and support the efforts to comply with new (Dutch) legislation on working environment and environment preservation.

Within the "Shipyard Development Programme" a project was initiated which aimed to:
- develop an integrated approach to the care for quality, working conditions and protection of environment
- develop the necessary supporting documentation in the form of a computer aided system
- set up and execute a pilot implementation

The above computer aided system will be further referred by its (Dutch) acronym COSY.

3. FROM LEGISLATION TO MEASURES: THE CONVERSION PROCESS

The process of converting legislative and other requirements into ordered and documented measures was analysed following a top-down approach. In total, eight different steps were identified (fig. 1):

1. Company programme
   This involves the definition of company goals and the determination of all organizational functions, technical processes and activities which must be performed in order to achieve these goals.

2. Control programme
   This is the framework for the execution of the programme which is defined by company policy, relevant legislation and other requirements. In other words, the governing conditions for executing the company programme.

3. Requirements programme
   This is a detailed specification of the control programme in terms of quantitative criteria, norms, standards, etc. which have to be met by the company involved in the execution of its own programme.
4. Programme of measures
This refers to the ordered set of measures which must be implemented in order to meet the requirements programme. Such measures can address policy, organization, personnel, procedures, work instructions, etc.

5. Programme of documents (documentation)
This is a set of ordered documents (system) which "reflects" the programme of measures and, likewise, can address policy, organization, etc. The system of documents must be defined, realized and implemented in correspondence with the measures.

6. Programme of changes
It is common experience that during the process of implementation measures and documents may have to be adjusted or changed. The programme aims to assure change control.

7. Acceptance or approval
In this step the effect of measures and documents is being investigated with respect to the established control programme. In other words, the ordered set of measures and documents, the care system, is being examined (audited) on the basis of criteria relevant to the control programme.

8. Evaluation
Changes in markets, legislation, technology, etc. can lead to changes in company programme and control programme; in this step, the relation between both programmes is being evaluated.

4. DOCUMENTATION SYSTEM
A key element in any system is the supporting documentation. ISO-standards address the matters of establishing, maintaining and controlling documentation in several of its articles (ref. 1).

In general, documents can be seen as information carriers to be used in communication, recording, reporting, prescription, description, instruction, authorization, etc. The functioning of an organization can be followed through registration and analysis of documents and document flow.

The ISO-standard refer in principle to two types of documents:
1. Documents which contain information related to resources, organizational functions, management activities, technical processes, etc.
2. Control documents.

The first type of documents is usually being used to support decisions which must be taken within any kind of process; decisions usually refer to acceptance of results (intermediate, final).
The second type of documents must assure the relevance, validity, quality and proper use of documents of the first type.

The framework for a documentation system can be represented by a pyramid structure consisting of four layers:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Document type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>policy documents</td>
</tr>
<tr>
<td>Second</td>
<td>organization description</td>
</tr>
<tr>
<td>Third</td>
<td>operational procedures and control</td>
</tr>
<tr>
<td>Fourth</td>
<td>instructions, norms, specs</td>
</tr>
</tbody>
</table>

(see also fig. 2)

The very "heart" of the documentation system lies at the third level, where the organizational functions are described by means of operational procedures. When the system is to provide a reliable representation of company functioning, the relations between documents of various layers and within one layer must be unambiguous.

The commonly used descriptive style (prose) for operational procedures proves to be a rather limited instrument when it comes to portray the functioning of organizations. Reference to other procedures, documents, tasks, etc. must all be deduced from texts which are occasionally supported by flow diagrams. The relation with control documents is not always clear and a lot of time is spent riffling through the pages of procedure manuals and the like.

A second difficulty arises when the system and its documents must be adjusted or changed. The impact of changes on the system must be traced through the relations between documents in order to maintain and assure system unambiguity.

5. COSY-DECISION MODEL

The poor operational efficiency of prose-style documentation systems has led to the development of a new approach which was used in the COSY-project. Based on a concept developed in the eighties (ref. 2) the description of organizational functions relies on a so-called standard decision model (STADEM), derived from the DEMING-circle (fig. 3).

According to the STADEM concept, control of organizational functions can be obtained by controlling decision making at crucial points within the functions. Decision making implicates acceptance of some sort of results following any kind of technical, intelectual or other activity.
By providing relevant, complete and correct information on time, conditions are created for good decision making provided that the decision maker is competent and possesses adequate authority.

The STADEM model includes the following eight decisions based on acceptance:
1. General requirements regarding final result.
2. Programme/plan regarding parts/components.
3. Specific requirements regarding parts/components.
4. Instructions regarding execution of parts/components.
5. Acceptance of intermediate results (parts/components).
6. Acceptance of changes to parts/components.
7. Acceptance of final results.

(see fig. 4).

Each decision must be supported by at least one document (or input), which is called main decision carrier (MOC); thus, one MOC per decision. If necessary, more decision carriers (DC) can be used.

The quality of the decision is significantly determined by (M)DC quality and its use; control of organizational functions can therefore be obtained through control of (M)DC quality and the quality of (M)DC use.

By introducing MDC-documents in the STADEM-model a standard description of organizational functions is obtained (STADOF, fig. 5 and 6). By introducing suitable terminology in the definition of decisions and MDC-documents, a model for a particular organizational function is obtained.

To assure proper control of organizational functions, the following elements are necessary:
1. Authority to take decisions.
2. Responsibility to prepare or provide all (M)DC and other documents necessary to the decision making process.
3. Assurance of (M)DC quality and proper use.

Elements (1) and (2) are covered by task allocation. Element (3) is provided by means of a so-called IID-document (information-instruction-description) which:
- includes information regarding (M)DC content;
- includes instructions regarding (M)DC routing.

IID-documents are in principle control documents. By specifying (M)DC content the following is obtained:
- the full extent of information required for decision making is determined;
- the specified information will always be available, regardless of the identity of the document maker.
(M)DC routing specifies the critical milestones through-out the making and using of the document as well as the department or person responsible for each particular milestone. A total of 10 milestones are identified:
1. Initiation of document making.
2. The actual making.
3. Check.
5. Distribution.
6. Copy.
8. Inspection.
9. Verification.
10. Archives.

The milestones describe the document lifecycle which is divided in two periods:
- milestones 1 to 5 relate to the making of the document (doc-period);
- milestones 6 to 10 relate to the execution of instructions laid down in the document (do-period).

Both periods form the so-called doc-do cycle (fig. 7).

It should be clear that by establishing IID-routing the tasks and responsibilities of departments and persons within the framework of organizational functions are unambiguously determined. The scheme of departments (persons) and related tasks is called Information-Instruction-Organization (IIO) matrix.

STADOF, IID and IIO are the principal models by which the functioning of organizations can be described within the COSY-structure. The location of these models within the pyramid structure of the COSY-documentation system is shown in fig. 8.

6. COSY PROGRAM

The COSY program was developed with the aim to "house" and manage integrated and/or dedicated care systems for quality, working environment, safety, environment protection, etc. Main system functions are (ref. 3):
- authorization; the program can be used by either:
  a. system managers (M), authorization unlimited
  b. system viewers (V), authorization limited
- insert and delete documents (M)
- fill in documentens (M)
- view documents (M/V)
- search for documents (M/V)
- draw up a list of catchwords (M)
- draw up a set consisting of various documents (M/V)
- help screens (M/V)

An overview of main and secondary menu's is given in fig. 9. The pyramid structure of COSY-documents is shown in fig. 10.
The main tasks of system managers is to fill in all COSY data bases and maintain (manage) the system according to the needs of the organization. To support these tasks a number of standard data bases have been provided:

- database organizational functions
- database IID-documents which are named "procedures" within the COSY-documentation structure.

The first data base includes a list of about 15, most common organizational functions within organizations involved in manufacturing of goods and rendering of services.

The second data base consists of an ordered set of procedures (IID's) which cover most activities within any type of organization. The procedures are divided into 10 groups:

<table>
<thead>
<tr>
<th>group nr.</th>
<th>title</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>management and administration</td>
</tr>
<tr>
<td>100</td>
<td>marketing and sales</td>
</tr>
<tr>
<td>200</td>
<td>finance</td>
</tr>
<tr>
<td>300</td>
<td>design and development</td>
</tr>
<tr>
<td>400</td>
<td>testing</td>
</tr>
<tr>
<td>500</td>
<td>purchasing</td>
</tr>
<tr>
<td>600</td>
<td>production</td>
</tr>
<tr>
<td>700</td>
<td>inspection, audits and acceptance</td>
</tr>
<tr>
<td>800</td>
<td>material management</td>
</tr>
<tr>
<td>900</td>
<td>(after sale) services</td>
</tr>
</tbody>
</table>

The first 8 procedures within each group are MDC-oriented, hereby assuring the quality of basic information for decision making. The system manager can use this database to fill in STADEF models for important organizational functions.

For specific sectors of industry and trade as well as for individual enterprises, additional standard data bases can be provided (norms, instructions, checklists, etc.). Hereby, the effort required to fill in COSY data bases can be significantly reduced. In principle, the number of documents housed in COSY should be limited to those which address critical or important issues in the functioning of the organization and/or require formal authorization, proof, etc.

7. STATUS AND FUTURE DEVELOPMENTS

The main COSY-models (STADOF, IID, IIO) are for some time being used in various configurations within QA/QC systems (processing industry, suppliers, shipbuilding). The complete COSY package for QA/QC applications has recently been purchased by various enterprises from trade and industry.

A pilot project regarding a limited implementation of the integrated care approach on a shipyard (Scheepswerf Visser B.V.) was started in January 1992 under the auspices of three Dutch ministries (Economic af-
fairs/Social affairs and Employment/Housing, Physical Planning and Environment).

Project monitoring and control is provided by a work group which includes specialists on care systems, QA/QC, safety, environment protection and information systems from:
- Industry (Netherlands Shipbuilding Industry Association, the Royal Flushing Group, Lloyd's Register).
- Delft University of Technology (Safety Science Group, Information Systems Group).
- Consultancy (Bureau ir. J. Leupen).

Based on intermediate results and conclusions (pilot project) several subjects for future developments have been identified; these are:
- extension of the number of standard data bases for specific sectors of industry and trade
- extension of help functions
- development of functions and data bases to support identification of statutory and other requirements, or the basis of a specified company program
- coupling of COSY with computer aided systems for project and/or production management and control.

8. CONCLUSIONS

Growing industrialization, trade and the resulting statutory and other requirements for quality, working conditions and environment protection have initiated a need (and a duty) for implementing so-called care (management) systems within enterprises.

Care systems consist of a set of ordered organizational and other measures which must assure that enterprises comply with requirements and demonstrate this ability in a convincing way.

To bridge the gap between requirements and the daily running of enterprises, a step by step conversion process was developed which matches company program (functions, processes, activities) with relevant legislation, market demands, etc. (control program). To obtain maximum efficiency, an integrated approach is used which finally leads to a likewise integrated set of measures and supporting documentation system.

The integrated set of measures is based on the principle of control of organizational functions. This is obtained by controlling and assuring the quality of decision making within principal organizational functions by means of supporting documentation.

The standard models for decision making (STADEM), organizational functions (STADOF), task allocation (IIO-matrix) and control documents (IID) for main decision carriers (MDC) are efficient means for developing and implementing supporting documentation for care systems. Hereby, a better operational efficiency with respect to
prose-style documentation systems is obtained.

Development, implementation, operational efficiency and overall management and control of the documentation system are further improved by using the COSY computer program. Program functions provide effective means for search, viewing, change control and program management whereas standard data bases for STADOF, IID and other documents support and reduce the effort required to fill in the system.

Considering the already demonstrated potential and the interest shown by industry and authorities, an increasing contribution by COSY to the development and implementation of integrated care systems is expected.

ACKNOWLEDGEMENT

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   report BOS.91.403.5.099, November 1991, Netherlands
   Shipbuilding Industry Association
From legislation to measures, an eight-step conversion process.

Pyramid structure of documentation systems.

Deming circle.

STADEM standard decision model.
Fig 5: STADEF: Standard organizational function model (principles).

Fig 6: STADEF: Standard organizational function model (complete).

Fig 7: DOC-DO cycle.

Fig 8: Location COSY-models in the pyramid structure.
Fig 9: Main and secondary menu's.

Fig 10: Pyramid structure of COSY documentation system.
Improving productivity in shipyards
J. van Sliedrecht

Statement: Labour productivity is less important than one thinks

I notice you think, this can not be meant seriously. It is, and I hope to explain to you why.
When a shipyard meets problems one of the first remarks made by the management is: "Productivity should be increased and the costs should be decreased".

In relation to "Productivity should be increased" the first thought generally is: "Everybody has to work harder". The second thought will be "Management has to organize the work much better, more in detail". The third thought will be: "We have to invest in machines, we have to mechanize, we have to automatize, we have to robotize.

Working out the first thought: "Everybody should work harder", means in many cases that management will hold speeches in canteens to motivate personnel to work harder, as well as personal talks. I can assure you, based on experiences, that this does not help at all. Maybe only for a short period.

The second thought "Management has to organize the work much better" means in many cases, at least in the past, that management decided to prepare more information in offices, to prepare more in detail and to give more detailed orders, having the idea that by doing that on paper the organization will improve. You know what I mean, line production, precisely written down in procedures, division of labour activity, bureaucracy, very very detailed planning, in other words an organization in accordance with the Taylor model.

If this is realised and a number of years later management looks back to the past years because of the fact that their competitors are still doing very well, perhaps better, management realizes that the result is much less than expected and in some cases the measures did not even help at all to improve the results of the yard.

What might be the reason? The disappointing situation is in many cases declared by management by saying that people are not doing their utmost, not willing to work properly, the organization of the work is poor.
Disappointed in "people" (remember this because of the second part of my lecture).

The second remark: "The cost should be decreased."
Of course this makes sense and to my opinion this belongs to the daily responsibility of the management.
But when this remark means:
- saving costs of maintenance
- saving costs of education and schooling
- saving costs of research and development
then management is making wrong decisions in the long term.

Why did I start this lecture so strange bearing in mind that it is a lecture about productivity in shipbuilding.
Mainly because many managers think that productivity only means making less man-hours in production.

I assume that managers know or feel that productivity has a wider meaning and has more than one meaning.

Maybe I should give a more justified academic explanation about productivity, but then my lecture will definitely be dull.
I will try to avoid this, that's why my attempt to simplicity.

Productivity is not the same as efficiency or in other words effectiveness.
Productivity free translated means 'fruitfulness'.

or
Productivity = \frac{\text{result}}{\text{efforts put in}}

We have to distinguish from the meaning of productivity:
labour productivity is \frac{\text{result}}{\text{efforts put in (in labourcapacity or tonnes)}}
capital productivity is result in money or similar capital per year
Naturally numerator and denominator should be a relation to work with to refer to because what is it all about in a company:
A) used man-hours
B) costs

In fact the most important for a company is the question: "How can we achieve the lowest production costs?"
More recognisable for us shipbuilders is:
the sum of man-hours x man-hours tariff + materials and services + a percentage for general costs and sales costs.

The graphics (enclosure 1) show how this is related to each other.
This subdivision differs, on one hand shipyards with more simple ships, particularly small series, in general man-hour related shipyards and on the other hand shipyards that are highly specialised or also a mixture of both which very often is the situation in the shipbuilding industry.

Also we can see from the graphics that from the total 'production costs' the number of man-hours as part of man-hours x tariff is restricted (limited percentage).

So it shows that when we try to improve the man-hours amount with 5% and the other aspects like materials and services are not under control the result is very limited.

I know it is a cliche, but I hope that with my presentation I can make clear that it is much more important for companies to take not only notice of the man-hours situation but also to decrease the tariff of man-hours as much as possible, to lower as much as possible general costs and sales costs and trying to get the best result by buying materials, components and services.

Again back to the subject of the lecture.

Of course, labour productivity has a direct relation to man-hours.

Discussing minimizing the amount of direct man-hours as part of labour productivity, the most important aspects are:

- good facilities
- good tools and machines
- mechanizing
- automatizing
- robotizing
- CAD/CAM
- planning and work preparation
- just in time approach
- production friendly construction of structures
- pre-outfit of ship sections
- building of units
- good organization
- qualified and motivated personnel

We can define the above mentioned aspects in 3 major groups:
a) hard-ware aspects
b) hard-ware aspects in combination with soft-ware aspects
c) soft-ware aspects

Group a) are investments in facilities, machines, tools and mechanization, in other words hard-ware.

That the yard should achieve the most optimal situation goes without saying.

One can speak of bad management if there is not taken care of these elementary aspects.

Group b) means automatizing, robotizing and CAD/CAM in other words the combination of soft-ware and hard-ware.
Buying and implementation of these subjects to decrease the amount of man-hours means very objective and careful judgement in respect of costs of the investments with regard to the profits. These investments do not always mean cost savings or in other words no capital productivity improvement, despite less man-hours for production. Also this group of aspects belongs in my vision to the normal activities, judgements and policy of the management. Also here applies that when a shipyard is not regularly busy with these aspects, one can speak of insufficient management. Unfortunately it is amazing that these aspects get very often less attention than necessary.

Of great importance in this group b) is the involvement of the personnel. When these investments with great influence on the way of working of the employees and the way the work is organized, are not well prepared and not sufficiently discussed with employees involved and as a consequence not properly implemented the expected results and advantages will definitely not be achieved.

Group c) are mainly aspects in relation to the organization of the departments and the way the work is organized as well as a relation to human involvement (software). If employees and managers
- see the importance of these aspects
- do completely agree with this policy and the way the organization has to be realized
- are willing to accept the implementation, the changes of the organization and the change in the way of working
- are willing to discuss organizational and work matters on equal basis and make good appointments about that

great improvements can and will be realised without major extra costs. A good organization together with qualified, motivated and involved employees are essential for a shipyard.

Everything said sofar makes clear that success is highly depending on people. Fortunately more and more managers realize that employees do not dismount their head at the entrance of the yard and mount their head at their body again when leaving the yard. The majority is able to do much more and complicated work than one thinks. Why do managers hesitate to delegate, to give more responsibility to the employees? Why are managers not willing to change their organization in such a way that responsibility and work are delegated into the organization as far as possible?
The answer to this is that it often lacks of courage and it also lacks of managers that are capable to implement this way of working together and to work in an organization with far delegated responsibilities, because the management should be ready and willing to change the organization from a functional production organization into a flexible product-orientated organization and way of working, giving the employees the possibility to be involved with the ins and outs of the yard in such a way making optimal use of knowledge of all people in the organization.

At IHC Holland we decided in the mid eighties after careful detailed investigations in relation to modern management to change from the said existing functional production organization to a flexible product related organization.

We named this process: Andere Werkvormen (free translated: other working method).

We as managing directors were completely aware and conscious of the deep intervention of this change in management style and the influence on the functioning of almost everybody in the yard.

The most important aspects of this approach are:
- as less organisational levels as possible in the organization
- delegation of responsibilities to the lowest possible level in the organization
- forming of production groups responsible for all aspects of the work that has to be carried out by the group
- bringing into the group all activities of importance to perform the given task
- more than one professional discipline in the group
- increased communication between departments not only horizontal but also vertical

The organization based on above mentioned aspects is realised and operational since 1987.

On the organization chart (encl. 2 and 3) you see the difference between the old and the new organization.

Into the group are brought together several professional disciplines including some detailed management disciplines (encl. 4, 5 and 6).

A few examples:
A group in the ships section assembly.
The ship section assembly consists of steel assembly, welding, grinding etc.
The group members execute all the activities for assembly of ships sections, fabrication assembly, welding, grinding, mounting of piping, units, cable trays etc.
Also the group is given the opportunity to determine the working methods in building these ship sections and to make a detailed planning.
The group is also responsible for the quality of the final ship section.
If quality is not according to specification and the next step is assembly of ship sections on the slipway, the employees at the slipway having problems, address their problems to the group responsible for assembly of the ship sections. In the group the ironworkers also weld and grind and welders do assembly work or grind etc.

Another example is a group that has the responsibility for outfitting a pumproom. The group consists of the next professions: pipefitters, welders, mechanical fitters, structural fitters, who, after discussion with each other based on rough planning and working methods, determine their working method and they also have the task to discuss with subcontractors to fit them in their activities. Also in these groups fitters do weldingwork or the other way around. The work of the groups are coordinated by a group coordinator. In many cases these group coordinators circulate, for project A mr. X and for project B mister Y.

Also in the drawing office the organization set up is based on products/orders (encl. 7 and 8) There is no mechanical drawing office and no shipbuilding drawing office. In the drawing office only a few people have a fixed desk. Depending on the work, groups of different disciplines are formed and located in such a way that they are in each others vicinity. The coordination as a result of this type of organization set-up is considerably improved and almost optimal.

Because of the fact that information necessary for the production based on this new organization set-up can not be too detailed the amount of paperwork is decreased significantly as well as the number of employees in these offices. In other words less indirect employees as the production does not need detailed planning.

Maybe you think, this can not be completely true, this is too nice and this can not be arranged just like that. Also it probably is a bunch of discussion groups and no working groups.

To start with the last remark, this is not the case at all. Shipbuilders do not like to talk much, are very practical and our experience learns us that discussions every now and then about the backgrounds, about things happening in the company, about the work situation etc. cost less time than to correct the situations where information was not available or not sufficient.

Indeed it was not easy to change the organization in the way as it is nowadays:
- Before implementation we made a very well detailed scenario what to do.
Our employees were informed as good as possible.
We discussed as much as possible the alterations with our employees.
A very important part of this change in management style and working together is schooling.
Approximately 80% of our production employees are capable to perform another profession.
Approximately 40% followed an internal course in elementary knowledge of planning, work preparation, organization etc.
Approximately 15% followed an internal course about elementary aspects in how a company is managed.
That means financial, economical and organizational matters and also how orders are handled (calculations, planning, work preparation etc.).

This approach appeared possible and indeed it is remarkable that the majority of our employees do a lot more than thought and are willing to bear more responsibility, are capable to work in this environment and are motivated, having more knowledge what is going on in the company.
Because of that there is more understanding nowadays among each other and between departments in a horizontal as well as vertical way and the communication improved.

About the remark: 'this is too good to be true, such a happy family. Of course it is not so beautiful or complete yet. In 1985 we allowed ourselves time till 1990. Now in 1992 we are even not half way of what we wanted to achieve. Not all groups work as described in this lecture. Not every employee is completely convinced of this way of working together. Every two steps forward means one step backwards.

But what we have achieved is very important:
- the organization is formed in conformity what I showed you
- the organization works, according to what I told you, despite a lot of limitations
- an important part of our employees is indeed capable to cope with the delegated responsibilities.
- the motivation has improved.
- the 'pikorde' has gone.
- multi-skill working has been improved and is not any more an item to discuss

and last but not least there is a major increase in productivity and costs are brought back to a level belonging to a yard that specialised itself in a certain market segment (enclosure 9).

FOR IHC HOLLAND THE POINT OF NO RETURN IS PASSED

Our employees do not accept any more that management tells them in detail what to do.
Our employees do not accept the hierarchical situation as before.
We are very pleased notwithstanding that what we want to achieve is still far away. Is it chaos, is everybody doing what he likes to do? Quite the contrary. Motivated employees and involved employees do not waist their time, so playing policeman as before is not the case any more which is of great importance for management.

One of the most difficult aspects of this other way of working has been the cut off of some hierarchic levels like foreman etc. I have to confess that this operation has been a little easier because of changing the company to a lower level because of the shipbuilding crisis in the seventies and eighties.

But even nowadays there is a lot of attention necessary from our managers to keep the proces of changing to a style of management as we implemented on the right path. It is worth to give so many man-hours and attention in the interest of the employees of the company.

Finally:
Of course labour productivity is important, but if you allow me to remind you once again to the formula in relation to "production costs" meaning:

\[ \text{man-hours} \times \text{man-hour tariff} + \text{materials and services} + \text{percentage general and sales costs} \]

that general costs and sales costs are kept to a minimum (naturally!?)
that purchasing materials, components and services is done at the lowest possible price against good quality (naturally!?)
that the man-hour tariff consists mainly out of direct personnel costs, indirect personnel costs and maintenance costs
that man-hour tariff is highly related to the way the company is organized especially in relation to the number of indirect employees
that decreasing the number of man-hours by facilities, machines, mechanization, automatization, CAD/CAM is part of the normal aspects of policy of a yard and in fact not too difficult (naturally!?)
that people and the way they are organized the way they work together and the way they are motivated are very, very important (naturally!?)

Means that only an integral approach of "means" and "men" leads the company to the lowest possible 'production costs', of which decreasing the amount of man-hours per unit as part of decreasing labour productivity is less important not taking into consideration the "self-evident" aspects.
So my statement: "Labour productivity is less important than one thinks" has quite a bit of truth.
Do not think we are a bunch of sociologists.
For managing directors it is important for the existence of a company that the company makes profit.
Therefore you have to invest in means and in people.
Do not forget to invest in "people".
We IHC Holland do.
IHC HOLLAND NV

YARD ORGANIZED FOR BUILDING OF "SPECIAL SHIPS"

YARD ORGANIZED FOR BUILDING OF "LESS COMPLICATED SHIPS" (PRODUCTION FACILITY)

MIX OF "SPECIALIZED" AND "PRODUCTION" YARD

(FORMER ORGANIZATION STRUCTURE)

MANAGING DIRECTOR

GENERAL MANAGER PRODUCTION DEPARTMENT

SECRETARIAT

WORK PREPARATION PLANNING "A"

MANAGER SHIP BUILDING

MANAGER SHIPBUILDING MECHANICAL

WORK PREP. CUTTING MACH. HAND.

SHIPS SECTION IRONWORK

SHIPS SECTION WELDING

SLIPWAY FITTERS

SLIPWAY WELDERS

FITTERS

CARPENTERS

MACHINING

FUNCTIONAL STRUCTURE "PRODUCTION"
IHC HOLLAND NV

THE NEW SITUATION IN HER MOST SIMPLE SCHEMATIC FORM

MULTI - SKILL ACTIVITIES
IHC HOLLAND NV

PERIODS OF IMPROVEMENTS DUE TO:

<table>
<thead>
<tr>
<th>NEW FACILITIES</th>
<th>PREFAB UNITS, PRE-OUTFIT</th>
<th>'ANDERE WEREVORMEN'</th>
<th>'ANDERE WEREVORMEN'</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.C. CUTTING</td>
<td>NEW SHIP SECTION ASSEMBLY</td>
<td>MAINLY MULTI-SKILL</td>
<td>MAINLY ORGANIZATION</td>
</tr>
<tr>
<td>COVERED SLIPWAY</td>
<td>NEW FACILITIES</td>
<td>OF GROUPS ETC.</td>
<td></td>
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</table>

NEW PANELFLOWLINE

YEARS

LABOUR PRODUCTIVITY

Examples from the automotive industry for ship production
R.W.F. Kortenhorst

0. Introduction

0.1 The Far East cultures: better for industry than the western?

Industries like the automotive, the optical/photography, the electronic and the shipbuilding can hardly be compared to each other. Yet, in the western world, one thing can be mentioned as very comparable for each of them: all these industries suffer a severe competition from their Far East colleagues. In quality, industrial performance and in keeping their technology up to date, the winners are nowadays mostly found in the Far East areas.

Industries in the West, of course, didn't keep passive. Many study-tours have been organized, and many consultants have earned lots of money while dealing with the magic question 'How do they do it that good?' Lots of 'eastern' business sciences and management tools have been introduced into the western industries, many experiments took place. Unfortunately they did not yet result in again our companies becoming the world's most modern and most competitive ones. An oftenly heard explanation for this failure to introduce here the Far East 'business tools' is that 'their culture is different'. If you listen to many Western managers, they oftenly explain the Far East success-story as being a result of a culture that:
- is typically suited for performing well in industrial activities and developments
- unfortunately is difficult to adapt by our West-European/ American cultures.

0.2 West-European people: successful in Far East companies

In the industrial expansion of the Far East nowadays we see that they start-up many industrial activities in the U.S.A.
and in West-Europe. Many examples can be given: Honda in the USA, FUJI in Tilburg the Netherlands, Mitsubishi now owning a one-third part in the former Dutch company 'Volvo-car', Hyundai opening companies in Europe, and last but not least: Nissan Motors United Kingdom (NMUK).

If the explanations given by the West-European and American managers are right, these new companies can't get as successful as their far east mother-companies. In our world these companies will deal with our people, having our culture and not theirs.
Yet, what we see is nothing else than......success.

Let us focus on NMUK: the company that launched the new NISSAN PRIMERA as 'a new European Car'. A company located in an area where only a few years before the largest tragedies took place that was ever seen in the automotive industrie. And a company working with the same British people as did the former British factories.
Yet a company that has really shown how 'success' in the European automotive industry looks alike.

The British in NMUK: did they become the far east minded people from the western world? Did they dramatically change their own culture?
No, these people still are as British as British can be. They haven't been brainwashed, and they haven't been selected by the far east managers on their talents in taking over other cultures.

The thing is: the Japanese managers recognized and accepted the strengths and the weaknesses of the Western culture, and adapted their management system accordingly. This, instead of trying to change Westerns into Easterns.

After having worked in the shipbuilding industry, during some recent years the author has worked in various management positions in the automotive industry. In closely cooperating with far east carbuilders he was teached how far east car companies deal with projects in the 'Euro/Asian' automotive industry in an effective way.

In this paper we herefrom try to derive some lessons for our own industry: ship engineering and ship production.

This paper therefore will cover the following subjects:
1. A conceptual model on 'projects'.
2. Some comparison between various ways of project
management, and amongst them: the way Japanese companies deal with projects that have to be carried out in a West-European cultural setting.

3. What can the shipbuilding industry learn from this?

1. A conceptual characterization of projects

1.1 Why 'projects' as the backbone of this paper?

If we analyse the process of the shipbuilding industry we recognize two main items:
- the processing of steel: from pre-processing of plates and profiles, until processes as welding, section manipulation etc.
- the process of controlling a project, starting from initial engineering, ending with the commissioning and delivery of a complete ship.

The first item, in many aspects, can be bought: equipment that improve productivity like CNC-cutting machines, modern welding equipment, panel lines etc. are available from many professional suppliers.

The second item however cannot be bought: it concerns mainly a management task, a way of approaching the profession.

This last item contains lots of potential 'winning' or 'loosing'.

It is the projectmanagement that defines the projects' lead time. It is the project- (and engineering-) management that enables a manhour saving pre-outfitting of sections. It is proper project-management that enables a yard to foresee production problems and, by foreseeing, enables to prevent them.

It is our own practical shipyard experience that tells us that the majority of lead-time and manhours that is experienced as 'lost' and 'unnecessary' is caused by bad projectmanagement.

It is the projectmanagement where we feel that the biggest improvement in shipbuilding performance can be gained. And, probably the most important thing: shipbuilding is nothing more and nothing less than dealing with projects. Projects in which a ship has to be developed and to be built within a limited time and a (mostly very...) limited budget. And in this job: it is projectmanagement that shows
how yard- and engineering- managers deal with their profession. This paper is written for these managers.

Therefore: we choose project management as the subject to illustrate the way far east companies implement successful business-operations in a western culture. As an example for the shipbuilding industry.

1.2 Projects: the art of scheduling and controlling of decisions

Technical projects can be defined as an integrated process of:
- getting through a huge amount of decisions to be taken.
- doing a lot of engineering, purchasing and building actions.

And all this where:
- many decisions are dependent on many others and on many of the actions to be done
- it is mixed up in a way you oftenly don't know in advance.

In other words: while managing your project, a scope of uncertainty needs to be eliminated. Only during the final phases of your projects no questions should exist anymore. See also picture 1.

![Picture 1: a model for projects](image-url)

- both decision-taking and actions
- only actions
- projects' results fully described
- project completed
- start lead time of the project end

scope of uncertainty

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For example: a part of the engineering process of a ship.

hull construction:
a decision needs to be taken: longitudinal or transversal framing. Then an action needs to be done: the drawing a construction plan.
Then a decision needs to be taken on...... etc.

ingine room installation:
a decision needs to be taken: propulsion system
Then an action needs to be carried out: select main engine alternatives.
A decision needs to be taken: what main engine will we choose?
An action needs to be carried out: further 'power train' to be engineered.

hull construction and engine room installation meet each other:
A decision needs to be taken: where and what kind of fundations?
An action needs to be carried out: further engineering to be done.
Once this engineering is ready: a good basis is available for many further decisions on the (detailed) engineroom layout.

Dear reader: please notice how many times the one decision/action is depending on the other decision/action !! (and please notice as well that if the integration of all these is not done right, that many corrective actions will be necessary in later building phases !)

picture 2: interrelated decisions and actions
Watching this example a project can be defined as a scope of interrelated uncertainties that need to be eliminated in a logic consequence and order, and in a logic relationship with many actions that take place within the process. See also picture 2.

Taking into account the given 'model' of a project: what happens if the project is not being dealt with as is called up for in this model?

First: something about the relation between costs and time in a project.

As we, shipbuilders, all know:
- the fitting of a roof-mounted ventilation duct against a deck that forms part of a deck-section laying upside down is much cheaper (or: gives the yard-manager more profits...) than fitting it somewhere far away in a ship laying at the outfitting quay.
- the changing of the position of, for example, a ventilation duct in an engine-room is much cheaper to carry out on the drawing board than on board of the actual ship.

So: what will a 'cost-thinking engineer' do: try to engineer the duct in such way that:
- he is early enough to enable the yard to fit it into the deck-section
- he is co-ordinating carefully his 'own' engineering with the engineering of other components that might require dramatic changes of the duct once fitted.

For the engineer (and for his colleagues !!!, and for the entire organisation !!!) this requires careful scheduling and a reliable co-ordination and co-operation.

Generally spoken: the engineer, and the organization in which he works, take into account two important 'laws' in project-management:
1. deciding too late means oftenly: deciding too expensive
2. deciding early requires utmost respect to the interrelationsship that exists between all the decisions to be made.

This means for the engineering management: careful identifying and scheduling the decision process !!

Let's go back now to the project-model as we discussed earlier.
Each decision, like the engineers decision above, can be seen as a mini-version of the model given in picture 1.: you eliminate an uncertainty and after that you carry out your action. In many cases the result of this actions forms the input for a new decision. By thinking like that, you can see the entire project as a structure of interrelated decisions. See picture 3., and for a detail of this structure: picture 4.

![Diagram](image)

- Picture 3: Interrelated actions/decisions
- Picture 4: Detail from Picture 3
What actually happens if:
- you decide too late?
- you decide un-coordinated and thereby causing yourself or other people to do their work again?

In these cases you make the scope of uncertainty exist longer. You cause that many decisions need to be taken in a later stage.
Within our model this is shown in detail in picture 5.

![Picture 5: delayed decisions.....](image)

Have you, operating shipbuilders, ever had sea-trials that took place while some problems still required a solution? (Thus: while some uncertainties still existed?) In terms of our model: have you ever been in a situation as shown in picture 6?

![Picture 6: consequences of delayed decisions](image)
As was illustrated in the example of the duct pipe: in many cases the action resulting from a decision may become more expensive if the decision is taken too late! This means that the decisions that are taken within the areas, indicated in picture 6 as 'expensive areas', cause actions that are more expensive than necessary if decided earlier.

Some conclusions can be drawn:
- A project is a complex of decisions and actions that have an intense interrelationship.
- During the start of a project this interrelationship isn't totally clear. The identification of this interrelated structure needs to be carried out as a separate action.
- Showing respect to this structure in managing the project engineering, in close co-ordination with all the other project actions, may result in an effective project realisation.
- Denying this structure however, will result in many under-optimal operations and may require the need of many expensive corrective actions.

2. Some ways to manage projects

In the following some different ways to manage projects will be discussed. These different kinds of project management will be illustrated by the conceptual model as was developed in the previous chapter.

2.1 The Japanese/far east way to manage projects

What do we see if we look to the way that projects are managed in Japanese organisations?

The first thing that is done is making up very detailed project break-downs. These break-downs form the basis for elaborating detailed project-schedules. In doing all this, many modern project management techniques are used like network-planning, computer programmes for optimal allocation of man-power. In many cases the schedules will anticipate to the use of additional modern management techniques like, for example, 'simultaneous engineering'.

Especially when compared with the western way of preparing a project the Japanese involve many people in making these
break-downs and, after that, in working out the project schedules.

Japanese project managers won't let a project start with the actual carrying out of the work before all these careful preparations are finished in good order. It is often seen that, in comparable projects, the Japanese start the actual work later than their western colleagues do.

In later phases the project will be carried out exactly according to schedules, which are of a high quality. If, due to unforeseen circumstances, a delay is expected, the managers will pay a maximum effort to get back to original schedules.

This way of managing projects is applied very strictly: if schedules say that all design work is to be finished, absolutely no changes will be accepted anymore. The result of this way of project management is well known: as was scheduled, a sure moment will be met that no uncertainties are left anymore, and only 'work' needs to be done. The projects will be realised in relative short lead time, and: according schedules.

Within the conceptual model as developed earlier, this way of realising projects looks like picture 7.

picture 7: Japanese managed project
2.2 The Western way to manage projects

In the (traditional) western way to manage projects, another approach can be recognized.

A very detailed project breakdown is not the first activity. The first actions the project leaders will focus on are:
- identify the typical leadtime aspects, start them up,
- identify the jobs that allow action soon, prepare them and start.

Of this approach many examples can be given. In the automotive the management is proud to have a first 'research centre prototype' running soon after the decision to develop a new type of car. In shipyards you had a reason to be proud if the first keel-plate was being laid only one month after order.

Generally spoken: the western organization focus on a quickstart of the actual work.

During the further course of the project much of the projectmanagement can't be characterized as a process of careful 'anticipated and scheduled actions'. Lots of the things to be done are indicated by the actual, physical progress of the project.

This consequently results in many decision to be taken in the later phases of the project. These late decisions oftenly result in an expensive way of carrying out the work. Especially during its later phases, this causes that the project is experienced as very difficult to control.

Then, of course, lots of manhours are being made that haven't been foreseen and scheduled.

A large amount of flexibility is required to realise the project not too much delayed from original schedules.

Happily it is a typical strength of the western culture to be that flexible: in the latest phases of the projects the impossible is turned into the possible. And finally, when the project is ended we, western managers, are proud of presenting the project by speaking like:

'...Especially taking into account the severe delays that were caused by some unforeseen difficulties, our company is proud of the flexibility that enabled us to deliver this project only four days later than originally scheduled....'

Using our conceptual model of project management, a typical western project can be illustrated by picture 8.
2.3 Westerns improving their project management....

Western managers, of course, experienced that the way of projectmanagement explained above, was far from optimal. As a consequence, many organisations tried to improve their projectmanagement.

What actually did these organisation do?

1. they introduced modern project management techniques as in common use in the far east industries. Techniques like network-planning, simultaneous engineering, project budget control etc.
2. they introduced programmes to improve the personal involvement of the individual employee.

The first thing was a clear question: if these techniques prove to be succesful over there, why shouldn't they over here?

The second thing was a logic consequence of choosing for applying these techniques. It was obvious that these techniques require a lot of discipline of the people involved.

Discipline can be obtained by two alternative ways:
- by force, law and order: 'If you don't...., I will .... you'.
  (.....: something very unkind to people)
  This approach won't work in the western culture.
- by creating a high level of personal involvement. It is hoped that personal involvement will motivate the employee to show respect to the discipline, required to apply modern projectmanagement techniques succesfully.

What was the result of all this?
1. Applying and understanding the 'new' management techniques as such wasn't too difficult, and was done properly according to the 'technical rules' in most cases. (As a matter of fact: it is interesting to know that some of these techniques are typical western inventions)

2. These techniques however did not result in an improvement of the performance of dealing with projects in an optimal way:
   Why? Even with highly motivated people the discipline, necessary to work with these techniques successfully, was bound to come. So: after an enthusiastic start-up many projects 'fell back' to the traditional way of project management: reacting in a flexible way to what the physical progress of the project tells you to do/decide.

See also picture 9: 'far east' techniques in western organisations.

2.4 far east companies managing projects in western companies

Looking to the way far east companies manage projects in their western daughter-companies, four main elements can be recognized:

1. The main schedules within which the project will be carried out is developed extremely careful. In this work modern techniques of project scheduling are extensively used.
2. Based on these schedules, all the main decisions to be taken are identified. All the leadtimes of the various aspects of (preparations for) these decisions are identified as well. All this will result in a reliable schedule for taking the most important decisions in the project. Derived from that the most important milestones to be met are scheduled as well.

3. For the further the schedules aren't as tight and detailed as could be expected when reading chapter 2.1. The detailed scheduling of actions is a matter for the people who actually will carry out the work.

4. The main element in controlling the project:
   - is not the monitoring of the actual progress of the project activities, and carefully prescribing the people what to do in order to keep on meeting all the schedules,
   - but is keeping a maximum pressure on the organisation to meet the identified decisions and the identified milestones. It is left over to those who do the actual work to decide how they do that work. (This is different from what is described in chapter 2.1)

This way of project management is shown in picture 10.

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![Diagram](image_url)
How does this look alike in daily practice?
* a careful project-breakdown is executed. The interrelated decisions/ milestones are being consequentially identified.
* the scheduling is done by projectteams in which representatives of all operating departments take part. These representatives play an important role in determining feasible leadtimes involved.
* All this will result in project plans in which clearly 'phases' can be recognized, and in which clear milestones/ decisions to be taken (and all the preparations that MUST be ready by then) can be indicated.
* These schedules form the boundaries within each operating department has to do their work.
* To motivate the organisation to meet milestones/ decision moments: - management puts extreme effort in monitoring/ putting people under pressure for meeting the milestones in a proper way. The daily progress of the actual work is a responsability for the people themselves.
  - sub-contractors' payment terms are intensively related to the meeting of the identified milestones and decisions. These payment-terms oftenly differ from what we traditionally see.

3. Some general conclusions

Comparing the above mentioned ways to manage projects, especially considering their operational performance, some conclusions can be drawn:

- Tight and detailed scheduling, and consequently working in accordance to that, requires a kind of discipline that isn't the strongest point of the western culture.

- Under condition that flexibility and the capability to work under pressure can be performed, working to meet milestones that can't be denied doesn't require a tight and detailed scheduling (people can do it 'their own way').
This flexibility and the capability to work under pressure is a strong point of the western culture in comparison with the far east culture.
- If decision-moments and 'milestones' are chosen right, and are being met, a very important condition for properly realising a project is fulfilled.

- 'Far east project management' requires detailed scheduling, detailed prescribing people what to do and a detailed monitoring of progress within these instructions and schedules.

- 'Western' project management requires:
  * careful identification of milestones and decision-moments,
  * and keeping the people sharply focused on meeting these moments, without describing too much how they should do that.

4. An example for shipbuilding?

4.1 Where to get the profits?

Talking about modernisation of project management for the shipbuilding industry may very interesting, it has no sense if we don't choose our goals right. In this discussion the goal is very simple: how to get higher profits out of shipbuilding projects when thinking about project management?

Taking into account the many discussions that take place about the shipbuilding process, the 'big profits' must be found in two aspects of shipbuilding:
1. Attainment of a high degree of pre-outfitting of ship sections, in combination of preparing the piping as much as possible under optimal production circumstances. (This means: if possible NOT somewhere in a corner of an engineering)
2. Reduction of the leadtime of the assembly, final outfitting and commissioning process.

These discussions won't be repeated. In this paper we recognize them as the goal that ought to be set for successful improvement of project management.
4.2 An example for the shipbuilding industry?

An interesting question now is: how should the shipbuilding process, including its preparation, look alike if it was managed according to the example from the automotive industry, discussed in chapter 2.3?

Parts of this process will be the following actions:

1. A detailed break-down will be made of the physical location of all components and systems throughout the entire ship.
2. Of all components the necessary main actions will be identified; the most important interrelationships between these actions will be identified.
3. (Meanwhile) the ship is divided into sections.
4. Action '1.' and '3.' will be brought together: components and systems will be identified per ships' section.
5. Meanwhile rough timing schedules about the section building process will become available.
6. Pre-engineering- and pre-outfitting action-schedules can now be compiled, based on the section building schedules. Techniques like 'network-planning' may be of great help in this process.

Considering the schedules for section building, 'milestones' and 'decisions to be taken' can be defined and scheduled. This will be done by extensive discussions in which all responsible people involved will join:
- project manager
- if possible: ship-owner representatives
- heads of various engineering departments
- representatives of class societies
- head of purchasing departments
- if possible: representatives of main sub-contractors
- main responsible people of the production/ scheduling departments

These discussions must end with feasible schedules of milestones that must be met by:
- the commercial people in their discussions with the ship-owner about matters that they have to decide about.
- the engineering people about the availability and sequence of their drawings
- the purchase people about the quotations that must be available within time-frames, about the orders that must be realised within time-frames etc.
- the suppliers (that will have their orders in time due to the above mentioned 'purchase-milestones'...)

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about when and what they will supply:
- drawings/ informations
- materials and equipment
- etc. etc.

These schedules must be comparable with an internal agreement: the discussions haven't ended successfully when there isn't agreement between all!!

For illustration: If the desire is fitting of the steering gear, including hydraulic pumps, into the aft ship section,

the following decisions/ leadtimes must be passed:
- (leadtime for) general decision of shipowner about type of gear.
- (leadtime for) selection of supplier/ type of steering gear and of hydraulic equipment
- leadtime for production and delivery of equipment
- (leadtime for) class etc. approval of engineering proposal
- engineering of fundations
- etc.

7. All these activities must be done as early as possible after the order has been signed. This requires firm management by the shipyards' managers: many of the people involved will be very busy with running projects!

8. Management of the further project will mainly consist of monitoring the meeting of the agreed milestones.
- if possible the contract must contain phrases that limit the decision time-span for the shipowner concerning the questions the shipyard asks him.
- during the project all milestones must be monitored and maintained strictly. This includes of course all the milestones in the engineering-, purchasing- and developing process!!

If problems are foreseen, all action and all 'management pressure' must have one goal only: no delay permitted!! In the case of inevitable delay: next milestone must be met according to schedules.
- create incentives for the sub-contractors: fixed relations between milestones and payment terms, penalties related to 'their' milestones, etc.
4.3 Feasible ? Conclusions

Two arguments are oftenly heared when discussing this approach:

1. the shipbuilding process is too complex, and too undefinable to work according to the policy of 'common anticipation' as described above. In shipbuilding oftenly unforeseen difficulties appear that show the unpredictability of this process.
2. even if the process should be definable: technically/ geometrically a ship is too complex to be succesful in pre-engineering in detail of installations and piping systems in advance.

A reaction:

1. It is the authors opinion that the shipbuilding process isn't too difficult to define/ schedule in advance to create the basis of a well controllable project. Lots of the unforeseen problems that shipyards face during the building process aren't caused by unpredictability, but by a lack of careful scheduling and coordinating the engineering process. These problems concern matters like pipes running through each other, not enough space to fit the right ventilation ducts, hydraulic pipes to be fit on a wall that has already been wainscotted completely etc. The actual problem is that the shipbuilding process, and especially its engineering process, isn't fully recognized as, and managed as, a project that requires intense coordination: in timing/ scheduling aspects and in geometrical/ technical aspects.

The far east automotive industry (and in many aspects the offshore industry) show that in large projects many of these problems can be prevented by careful applying project-management in the engineering process.

2. It must be recognized that the geometrical arrangement of a ship and its installations is sometimes extremely complex and difficult to engineer in detail in advance. In this aspect the shipbuilding engineering process meets difficulties that hardly exist in, for example, engineering of buildings or tunnels.

Two recent developments may however facilitate this:
- application of a modular approach: define geometrical 'areas' and 'pipe/ duct/ cable lanes' that are reserved for specified systems; in these areas systems to be developed as much as 'hook in' modules fitted on a frame.
This approach requires, of course, intense coordination between many people when dimensioning and allocating the various 'areas' and 'lanes'.

- Computer systems, that enable to make a projection of complete piping systems into a ships' construction are nowadays available. An example is the system as now developed by 'Engineering Centrum Groningen b.v.', the Netherlands.

These systems allow extremely detailed engineering of all ships systems within the ships' structure in 3D. It is obvious that modification of a 8' pipe is much cheaper on the CAD-screen than in a ships' engineroom....

Some conclusions can be drawn:

1. The process of shipbuilding can perform much better if it is recognized fully, especially in its pre-building phases, as a project that requires a projectmanagement approach.

2. In choosing a projectmanagement approach, you have to accept the people the way they are. Western people are different to far east people. Management approaches that are succesful in the far east won't be automatically succesful in the western world.

3. A projectmanagement approach requires that the project should be defined in advance, as a consequence of logic thinking by all people involved, instead of partially being a result of its own physical progress. Projectmanagement therefore requires a management choice: a choice to invest in an intense analysis of the process, as a basis (and an important condition !!) for defining and scheduling the milestones and decision through which the project will be realised.

All this concerns an effort in the start-up phase of a project that is new for many shipyards !

4. If this 'framework for project-control' is set-up properly, the shipyards' management possesses a reliable tool:
   - that forms the basis for engineering and pre-production required for extensive pre-outfitting of sections
   - to control the project, without interfering with the 'natural' way western people like to do their work: their own way.
Within this frame-work it is a management task to be very strict in not accepting delays and postponements.

5. The use of modern CAD-facilities, and the application of a 'modular' approach of engineering allows an additional high degree of pre-engineering, and hereby: of pre-outfitting.
Improving shipyard performance through specialization in production

Hengst

INTRODUCTION

The business of shipbuilding is influenced by many factors which can't be controlled by the management of a yard. Market conditions and (national) administrations influence the objectives and hence the strategy to operate and develop the enterprise. The volume and conditions of the shipbuilding market are subject to considerable changes in few years periods. The role of national administrations, unions and e.g. systems for social care differ substantially from one country to another. Management has to organize, structure and finance the production process, considering these external factors. Specific skills and tools are under such circumstances required to manage a shipyard operating in the world market.

Literature and standard handbooks do not offer much help to formulate a strategy and to develop a competitive marketing, sales and production organization for a shipyard.

A fundamental problem is that the forces driving the competition between shipyards, as e.g. described by Porter (1), cannot be compared on world scale:

- Cultures, labor conditions, industrial infrastructure and environmental ruling differ from continent to continent or country to country, and even from region to region.
- For substitute products the same remark can be made.
- The development of the industrial infrastructure depends on national policies and the relevance given by a government to the maritime industry as well as the priority given by the administrations to create favorable industrial conditions in a specific region.

Shipping and shipbuilding are cost-driven businesses:

- New entrants, i.e. low (labor) cost builders will continue to influence international competition.
- In a well developed second hand market shipowners with relative low capital investments are competing with "first class shipowners", operating with efficient, high-tech vessels.

Shipbuilding calls, under these circumstances, for the capability to meet individual commercial and technical wishes of a client in combination with a flexible organization able to respond to the demand.

The external factors should motivate shipyards to a continuous valuation of the production methods and facilities. The research in ship production should have as first aim cost reduction. Reducing building time means reducing costs for the shipowner.

The operating conditions for a shipyard should be considered simultaneously e.g.:

- The pressure to realize shorter lead times is increasing.
- Capital is difficult to raise if returns on investment are unstable or difficult to predict.
- The increasing complexity of ships requires higher and better educated people on ships and in shipyards.
- The importance of organizational and social values grows. A result of the demand for flexibility and well trained people.
- The pressure to decrease manpower with the aim to minimize
risks in an unstable market.
Emphasize is put on governmental ruling to improve the work conditions.

The conditions are in some cases conflicting. Shorter lead times usually require an increase in manpower-capacity of the shipyard. This is in conflict with a policy aiming at decrease in manpower to reduce the risk of overcapacity during periods of a cut back in demand. Reduced delivery times are prime importance for the shipowner, but are a problem for the traditional shipbuilder with a limited capacity (fig. 1).

Reduction in lead times attainable through e.g.:
- increasing the productivity of a single yard
- maximizing flexibility of labor between departments
- subcontracting production capacity with other yards
- sharing specialized production capacity with other companies
- increasing the productivity of the organization
- simplifying the production etc.

In order to be able to judge advantages and constraints of the (combination of) solutions a detailed look into the production system of a shipyard is desirable.

Incentives are suggested to develop new technologies, improve products and productivity, change the structure of the industry. Programmes are proposed to explore reductions in cost, ameliorate quality and generate new solutions with the objective to run business more competitively.

However, the validation of an idea requires a preferably simple tool enabling an individual shipyard to evaluate changes in production system. It demands the availability of a reliable prediction and evaluation method, considering the effects on:
- cost, lead-time and quality of the product and
- profitability of production process to assist the management with a decision support tool.

The effects of specialization in combination with an autonomous operation of parts of the production facilities may be an answer to improve the performance of a production system and are discussed in
A review of the opportunities described in the literature to improve the market position of a business in general terms. A description of distinct production systems which can be defined in shipyards. The systems are reviewed indicating limits, opportunities and requirements associated with the key functions of a shipyard.

A method to predict and measure performance in terms of cost, delivery time and quality.

**ECONOMIES OF SCALE**

Methods to reduce cost and improve productivity or quality differ considerably and are amongst others depending on the market position, the structure of the industry and the production system. Reas which are usually indicated for further investigation to improve competitiveness are:

- Relations and communications of the management with labor.
- The search for possibilities to create entry barriers for the competition.
- The evaluation of the structure of the industry i.e. the relationship between shipyards and suppliers or subcontractors.
- The organization of the production.

Rankel (2) gives some guidelines and recommendations to improve the competitiveness and productivity of the shipyards in the United States. These views are of particular interest when the present position of the shipbuilding industry in the U.S. in the market of the merchant marine is taken into consideration.

Oster (1) describes some sources to create barriers for entry to an industry.

Economies of scale can be found in any functional area or part of a business. The goal of economy of scale is to reduce the unit cost of a product or a part of a product.

- Examples are R & D, manufacturing, industrialization of production processes (prefabrication or panel-line fabrications), combining capacities to increase output, improve quality, implementation of new technologies and the reduction of joint costs.
- Vertical integration, the successive stages of production or distribution are in one hand or combined. This refers to the association with subcontractors and equipment suppliers. Apart from technical and organizational cooperation techniques and means to reduce cost could be part of the teamwork. However, in practice, it is nearly impossible for a shipyard to restrict the supplier or subcontractor to use the jointly developed know-how elsewhere.

Capital requirements.

An entry barrier to the market is the need for capital requirements. This can be cost for research and development, but also investments for new technological developments.

Cost advantages independent of scale.

- Favorable access to raw materials.
- Convenient geographical locations.
- Proprietary product technology. In shipbuilding and shipping
it is difficult to protect product know-how by patents or proprietary agreements.

- Learning or experience curves
- the development of standards are leading to cost reductions.
* Government policy.

A government may limit the competition and initiate entry barriers by supporting the industry, implementing rules for environmental standards, product safety etc.

Benefits of specializing parts of the production system are generally resulting in decreased cost per unit, cost advantages independent of scale and capital cost.

The classic learning curve is the result of experience through specialization. Improved working methods, a refined lay-out and use of equipment, increased performances of labor, better dimensional control with appertaining measuring techniques are resulting in declining costs per unit and improved quality (3).

The general view is up till now that for the type of heavy construction work as shipbuilding not much can be expected from dimensional control in the assembly stages. The dimensions of large assemblies are difficult to control due to the deformations during welding and assembly, resulting from heat-input, transportation, insufficient homogeneity of the material, lack of repetitive work etc.

INTEGRATION OR DIVERSIFICATION

The traditional shipyard is based on vertical integration i.e. the fabrication of as much equipment as possible: castings, turbines, main-engines, foundries, machine-shops, pipe-shops, carpenter work. It includes nearly any type of work required to build a ship and adding value to shipyard production.

Advantages of vertical integration are found in the reduction of joint costs, resulting from economy of scale. Overhead costs are spread. The production process is in one hand. Delivery times can be controlled by employing (own) spare capacity and subcontracting when capacity is short.

This diversification puts also constraints on the effectiveness of the process. The balancing of the capacities of the departments in the flow of the process is difficult to achieve. Efficient use of investments in production facilities in a single department, e.g. through an increase of the production volume to maximum available capacity, may not be possible. The opportunity to obtain reductions in cost per unit remains unused in case capacities cannot be balanced. Particularly in case of process-type or batch type production systems, cost reductions are not realized when the production of a unit is limited to the demand of one shipyard. The total production system does usually not allow for levelling the production capacities of single departments. Moreover the degree of utilization of equipment and machinery will vary as a consequence of different types and sizes of ships which are subsequently under construction. The production system is under these conditions faced with additional costs which have to be accepted.

Specialization of subcontractors and suppliers initiated a change in the industry and made it possible to buy an increasing amount of equipment and installations from outside suppliers.
The process of specialization and horizontal diversification took place in the industry, without effecting the position of shipyards. The result was a different industrial infrastructure. "Make or buy" decisions became a relevant topic for a shipyard to be able to reduce costs (6).

The shipyards concentrated on what can be considered their core production activity. Production capacity became a matter of the combination of available manpower and physical capacities, building any type of ship and trying to cover new markets. At the same time some yards specialized in specific markets and types of ships. In the Netherlands the advantages of product specialization were successfully exploited by a number of yards.

The process of specialization and horizontal diversification is continuing. To explore where further progress can be achieved, the effects of improving the quality in the up-stream stages of the production process (engineering, purchasing, material handling, prefabrication) will have to included in the evaluation and weighed with regard to the impact on the production stages down-stream the process, e.g. the assembly.

The required capital demand up-streams, as sophisticated computer applications, could be limited when combined purchase and shared operation are envisaged. The same applies for costly up-front R&D and software development. A decrease of the cost per unit is than feasible. The problem of inter-dependability is not necessarily a commercial but often a psychological factor. The assurance of the persistent competitive attitude of a combined "service tool" needs attention.

The advantages of horizontal diversification are: spreading of capacity and increased flexibility, maintaining the capability to realize short lead times.

The attitude, bargaining power and the strengths and weaknesses of the suppliers to the shipbuilding industry deserves attention. The shipbuilding industry is usually not an important customer for the suppliers because the market volume is limited compared to the total sales volume. The relationship between equipment suppliers and shipowners is creating switching cost for both shipyards and shipowners (e.g. paint, navigation equipment or propulsion systems). The position of the shipyard can be weakened and the yard may investigate the possibility of vertical (backward) integration. On the other hand the cost of the product of the supplier often represents a small part of the total costs of a ship and the penalty for failure or late delivery may be high in relation to its cost.

The building of the steel hull, which represents approximately 75 % of the added value of a shipyard to the cost of a ship for the merchant marine, is one of the core manufacturing activities of the shipbuilding industry. The aim of some (e.g. Japanese) yards is to reduce the added value of the yard from 30 - 35 % of the total cost of the ship to 10 - 15 % in the coming years. Most of the cost related to the production of the steel hull are in assembly. It means that much attention should be given to this part of the production flow. The well organized assembly is another major area to be investigated.
PRODUCTION SYSTEMS AND SHIPYARD ORGANIZATION.

The objectives for a business in terms of profitability, market share and the operating conditions for the company under prevailing market circumstances shall be well-defined. Christensen and Andrews (5) formulated and investigated the concept of an explicit strategy for a company. The combination of target means and people defines the relationship between the strategy and the operational attitude of the management.

The tools to realize the objectives are, according to Andrews and Christensen:
- target-markets for products and product development,
- products which the company will have to develop or actually producing,
- research and development for product- and product development,
- marketing (as one of the major preparatory functions) for product development,
- sales,
- manufacturing,
- labor,
- purchasing,
- finance and control.

The specific articulation of the operational instruments by the management depends on the nature of the business. As remarked earlier not much is published about the shipbuilding industry. Generally it is said that "the organization will depend on the nature of the business" and that management may be more or less specific in defining the operating policies for the key functions and from thereon shape the organization to the purposes of the company.

Each activity of an organization involves cost. Cost that must be financed from the profit generated by that activity. Any activity in a diversified production process, which is subject to changes, entails the risk of potential losses. Insight in the key functions of the process is needed to be able to minimize risk and generate profits utilizing the required human-, physical- and capital resource.

"Production is not the application of tools to materials." It is the application of logic to work. The more clearly and rational the right logic is applied, the less of a limitation and the more of an opportunity production becomes", according to Drucker who developed some principles of production based on distinct rules, requirements and features (4).

**Differentiation in production systems**

Unique product manufacturing can be recognized by the organization of the work by homogeneous stages. The production organization is dependent on
- the type of product,
- the application of standardized tools,
- the use of standardized materials.

Unique product manufacturing demands a relatively low capital investment compared to the cost of labor. Cost per unit are high...
but break even points low. The organization must be flexible in order to make it competitive.

The characteristics of series or batch production are close to unique manufacturing. Sometimes the organization of the work is arranged as line production. The use of standardized parts is introduced, next to the application of standardized tools and materials. Series production is less labor-, but more capital intensive per product than unique product manufacturing.

Process production can probably be described the best by "producing in an integrated system, sometimes starting with one basic material, in one single process, different end products". Examples are process industries and transportation or distribution systems which are based on the same principle. The process is rigidly fixed and can hardly be changed: The production process is the integration of process and product, the production volume is high. Compared to unique product manufacturing and batch production the process industry is not labor intensive.

For each production system the organizational -, capital -, labor - and requirements for the key functions, as described by Andrews and christensen, seem to be different. This is relevant for the qualifications for personnel, the requirements for the physical resources, marketing and sales as well as the style of management. Although the key functions are the same for different businesses, the qualifications for the functions vary with the production system. Recognizing the type of process is apparently an important actor in organizing the production system which is defined as the total process i.e. marketing, sales, manufacturing, purchasing, finance and control etc. By organizing (parts of) production according to the principles of each system and learning how to apply and harmonize those systems within a production process, it becomes possible to advance the whole process.

The principles to improve production performance and pushing back certain limitations of the production systems are:

- Consistent and thorough application of the principals of the system in use.
- Awareness of different degrees of complexity of the systems;
- Unique-product production is usually called the least complex and process (flow) production the most complex.

The traditional building of the steel hull - as unique product manufacturing - is described as a labor intensive activity. The production process has certainly been improved by introducing new manufacturing technologies. Cost savings have been mostly realized by improving the up-stream stages in the production process such as numerically controlled processing of the prefabrication, panel-line assembly, pre-outfitting of blocks etc., without however changing the basic structure of the shipyard.

The possibility that there might be different types of processes within the overall process of ship production was not investigated. Moreover the development on the application of new technologies or processes for production equipment for the shipbuilding industry is primarily done by equipment suppliers, e.g. welding, cutting,
numerically controlled machine applications, etc. In shipbuilding this part of the production technology is available to the world market. Under these conditions, one of the core activities of the industry relies, to a great extent, on the results of Research Development which are available to every shipyard in the world. On the other hand history proves that advanced technology is not the prime mover for competitiveness and insufficient to be competitive in the market. Neither is the cost of labor, as is being proved by the current developments. This is another reason to consider the process of ship-production in relation to the infrastructure of the industry and the different types of processes.

**Research for production at the Delft University of Technology**

The goal of research in ship production carried out by the Technical University of Delft is defined as "find potential for reduction in cost and lead time and improved quality by studying the changes in the industrial infrastructure, production methods and organization of the shipyards as well as the construction of ships".

The systems explored —on a limited scale— as a part of the overall production system, in cooperation with some shipyards are:
- unique product manufacturing,
- batch and series manufacturing and
- process production.

The identification of the different types of processes is used as a starting point to study parts of the production process. The total cycle design-engineering-fabrication is explored.

The research is related to:
- The development —learning to know— of the specific possibilities, requirements and limitations of each system.
- The organization of the production according to the principles of each system.
- Learning how to apply and harmonize the systems within a total production process.

Different parts of the shipbuilding process are being studied with the aim to verify the features of the production systems and to establish if, and under which conditions, the principles of production outlined above are applicable and could serve as a tool to advance the total system.

The purpose is not to make studies or to measure the individual performance of welders, steel workers or other trades. The various stages of the process are divided in storage, transportation and manufacturing. Production flow and "product" are analyzed. Process analysis includes the evaluation of time spent on searching for materials or available information, set-up and preparation, effective working time and time lost for reasons beyond the control of the worker. The "product" is in this case not the ship, neither a distinct component or piece of equipment, but that part of the construction or assembly that can be identified and observed during the work. It may be the fitting, installation and welding of a penetration, the fitting and preparation of a part of a bulkhead for welding, the welding of a part of the structure. The purpose is to identify families of jobs, types of processes etc. to enable identification and comparison.
Why this approach?

The structure of the shipbuilding industry in the Netherlands makes it possible to explore different types and sizes of shipyards and organizations. Shipyards covering the entire production process having all the above mentioned operational instruments on one location up to enterprises which combine various specialized companies and jointly represent the -conventional- shipyard. Small and medium size yards with varying markets, from yachts to naval vessels, sometimes combining repair and newbuilding, provide for a versatile shipbuilding industry in the Netherlands, covering the international market.

When companies are grouped in a holding or similar organizations, independent operating businesses as well centralized organizations can be found. When it is considered useful from a business point of view and economically attractive key functions of an organizations may be combined. The aim is to link the effects of economies of scale and cost advantages independent of scale originating from experience and shared operations.

Some shipyards generate, very successfully, new technologies. The technology is marketed and sold to the industry independent from the shipyard.

Simultaneously this situation entails limitations for the research. To mention some:

- It is not possible to study repetitive identical "tests" or processes. The effects of e.g. a change of one parameter of a in the process cannot be measured.
- The variation in "products", offer a limited possibility to study identical products under identical conditions.
- The differentiation in departments and trades increases the above mentioned effects.
- The methods and equipment in use differ (size, capacity, type) from yard to yard.
- Production flows vary with the lay out of the yard.
- The ships under construction are not the same.
- The organizations of the yards, including the method of subcontracting are not comparable.
- Observations are limited in time, for practical reasons.

Although also apparently similar shipyards are involved, the organizations appear to be different. The conclusion must be that this type of research cannot be made under ideal laboratory conditions.

These considerations are leading to the present approach. By identifying:

- similar types of production systems and
- families of similar products,

in combination with labor and equipment involved, an attempt is made to come to a systematic analysis of different processes.

Aspects to be taken in consideration are:

- planning and material distribution,
- administrative systems,
- comparison and evaluation of working methods,
- manhours in relation to the use of materials
- the involvement of subcontractors and sub-suppliers,
- methods used to increase capacity etc.:
Quality and safety.
To be able to measure quality and safety industry-wide, norms and standards are required as well as references to determine the "value" of quality and safety in terms of money. There is no purpose in promoting quality in cost-driven industries if there is no relation to a financial reward. The well-developed second hand market is prohibiting the introduction of quality in transportation when safety is not an immediate concern. Safety is the result of commercial evaluations and only in a few cases related to public appreciation. Safety is in the first place related to performance of people and in the second place to performance of equipment. The quality of the product and the quality of the worker are interrelated and cannot be separated. Without suitable norms and standards which make it possible to measure and compare, quality can only be measured by using administrative procedures of determining the performance of the product. Again, the role of the classification societies as well as the insurance companies is crucial when performance of ship and crew are to be measured. Complicating factors are the life time of a ship (up to thirty years or more), changing ownership during the life time of the ship, the different modes of operation and exploitation, varying environmental conditions, different modes and attitudes toward maintenance etc. These conditions make that tangible results of projects as NEUTRABAS (9) and ROCOCO (10) remain to be seen particularly when the "life cycle" of the ship and process-modelling for CIM appear to be leading reasons to develop complex and costly computer software where simple and cheap tools are required and available. The question is under which conditions this type of supporting tools is indeed reducing cost or lead time. The quality of shipyard production is depending on two main factors throughout the total organization. Knowledge and people are the assets in design and engineering, but even more on the shop floor. Experience, training and education are the crucial factors.

Some results.

The different production stages are shown in fig. 2. The twelve stage are combined in five groups. Engineering (stage 4) include purchasing and is, with work preparation, considered as supporting activity for production. So far only the stages in group 1 and group 4 have been the subject of observations. The targets for engineering and work preparation are usually the result from planning for production. The activities of the production departments depend on the master planning of the yard. The parameters controlling the lead time for the work of each group are different. Groups 1 and 2 are primarily controlled by the availability of (external) information, the lead
times of group 3 are governed by the production capacities of equipment while the lead times for group 4 and 5 are depending on the delivery times of the (long lead) equipment, the manpower capacity and the equipment capacity in terms of transportation.

The observations made so far indicate that the manufacturing activities in group 3, i.e. material handling and pre-fabrication as well as panel line production have the characteristics of process-production, while assembling can be considered as unique product manufacturing, with the particularity that the activities of certain trades show aspects of batch or series production. The operations of group 3 are part of the manufacturing of the (steel) hull and are totally different from the unique production process. This indicates that there is a chance for specialization if the preparatory activities of group 2 are able to meet the demands from this part of the process. This includes not only the ordering of steel and the preparation of the numerically controlled fabrication of plates and profiles but also the timely and precise grouping of all materials required for sub-assembly.

Assembly (group 4) and fabrication (group 3) are putting different requirements on engineering and work preparation. The organization for assembly demands a specific approach for grouping and handling of materials, partly resulting from the previous stages in group 3 and simultaneously directly depending on engineering and purchasing actions. The observations show that there is considerable room for improvement compared to the activities in group 3.

The observations confirm the views of Schonberger (3) that the lead time is the governing factor for costs. Progress can be measured, according to Schonberger, by controlling two conditions:

- All materials for a product going to the shop floor.
- The finished product leaving the shop floor.

This type of control is only feasible if the lead time for production is a few days. The administrative and supervisory procedures are simplified. For a shipyard this is not a realistic condition for all the production activities. A simple method for longer lead times was developed in cooperation with a shipyard in the Netherlands. The method is also based on the material flow registered from the warehouse. Materials, manhours and lead times are estimated and combined, based on manhours, materials used in trades and departments for previous ships. The analysis indicates that the various activities of a shipyard can be characterized by curves having different shapes (fig. 3). By breaking down the ship into blocks and installations, it becomes possible to control progress,
indicate where certain delays in production can be expected which require corrective measures and assess at any time the actual materials and manhours spent in relation to the progress of work against the original estimates.

From the distribution of manhour and materials different types of curves can be established which are characteristic for certain trades and departments. (fig. 4)

Strategic selection of production development.

The selection of production activities for a shipyard - i.e. make or buy decision - shall be based on an analysis considering the aspects of cost, lead time and quality simultaneously. A shipyard has to decide which parts of the production are to be considered core activities of production, essential for the continuity of the company. The preparation of such decisions requires tools for management to be able to evaluate and compare different options and develop solid financial and economical policies.

The basics for such decisions are depending on conditions which will vary for each individual shipyard. Some of the variables to be considered are shown in fig. 5.
he numbers 1 through 5 in the figure refer to the groups mentioned in fig. 2. Although the variables displayed in fig. 5a show the same trend, only the potential to reduce cost can be estimated in terms of money. The effects of sub-contracting and cheap labour are easier to verify. Fig. 5c indicates that capital requirements for new technologies and potential for innovation have different effects. Capital requirements can be reasonably well estimated. The effects shown are related to the total shipyard operation. Groups 1 and 2 seem to include essential operations for a shipyard as well as groups 3 and 4. The in depth evaluation of a shipyard operation requires a tool enabling management to weigh the effects of any change into expected profits for the company and improve the competitive position. With the help of the type of variables as shown in fig. 5, financial modeling can support these evaluations and translate actions into a long term financial perspective.

Final remarks.

Design and engineering are crucial activities for a shipyard. The data base for production information is prepared during the engineering stage (including purchasing). The tools to support production can be simple, cheap and easy to maintain as long as the information required for production and accumulated during the engineering phase is limited to the needs of production, no more no less.

For the shipyards it is worthwhile to pay more attention to the R&D in manufacturing and assembly technologies which means:
- logistics,
- material handling,
- development of logically composed, system oriented, packages which are suitable for easy subcontracting, development of standards for engineering,
- more "containerization" of installation work,
- the development of "user friendly" software, for data bases containing the information from engineering for production.

It is recommendable to analyze the competitive position of the shipbuilding industry in Europe in the same way as has been done for the automotive and airplane industries. Studies of the automotive industry revealed unexpected high differences between e.g. the Japanese and European costlevels. Similar studies, on a smaller scale however, indicate that the shipbuilding industry in certain European countries i.e. Denmark and The Netherlands is much more competitive on a worldscale than the automotive industry (6). The remarks made by Sverdrup (7) deserve attention.

The dangers of an unbalanced industrial infrastructure are becoming visible when economical performances are compared for existing industries considering a multi-dimensional industrial structure as described by Porter. Apparently the statistics of economists do not have the possibility to produce information on e.g. a three or four level deep client-supplier relationship without disbanding the present statistical structure.
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A methodology for evolving cost and safety effective ships
Ch. Kuo

ABSTRACT

The paper begins by outlining the marine business environment before stating the basic requirement of the shipbuilder's customers. The term "cost and safety effectiveness" is explained and the contributions of interested parties are summarised. In order to achieve it, an approach is proposed based on establishing the ship's life-cycle and then applying the PREVENT-IT safety methodology to each phase while also incorporating the cost criteria. Basic stages of the approach are used to illustrate its application. Key conclusions are, first, that a positive attitude is needed in dealing with cost and safety, and secondly, that by using the proposed approach, it is possible to achieve cost and safety effectiveness in ships that meet customers' specifications.

THE MARINE BUSINESS ENVIRONMENT

Anyone connected with marine activities can appreciate the special characteristics of this industry: its cyclic and international nature, capital intensiveness, competitiveness and dependence on the level of world trade at any given point in time. Much less well understood is the long lead-time needed between an idea's conception and the generation of cashflow, and the narrowness of the profit margin in this industry where building up reserves requires large volumes of business.

To forecast future development accurately is an extremely demanding task but success depends very much on the ability to respond positively and speedily to the few attractive opportunities on offer. In order, therefore, to make at least an attempt at identifying the likely direction of marine business in the period up to the year 2000, we must make good use of all available information and learn to read the signals regarding future trends.

It is very clear that the business world is moving towards ever greater globalisation and decisions made in one part of the world, e.g., the Far East, will have an immediate and significant effect on the rest of the world. Planning must increasingly respond to market demand and organi-
zations will need the ability to meet it effectively. The customer will also want a range of choices. It has been argued that for success in this environment an organization must have the right market, management, money and manpower (representing all human resources), and also ensure that these four M's are developed in a balanced way at all times, see (Kuo, 1992).

The marine industry customer will increasingly be specifying high quality, coupled with cost effectiveness and an acceptable level of safety in relation to both human life and the ocean environment. This will put high pressure on technically trained staff to innovate, and even to invent solutions which will be more satisfactory. There will be no shortage of data or techniques but learning to prioritise alternatives is essential as it will not be possible or desirable to consider all options in detail.

The role of the providers of maritime education will be crucial, as everybody with a contribution to make - especially future graduates - will have to combine technical capabilities with a proper understanding of the commercial implications of their decisions. It is only thus that we can expect to evolve cost and safety effective ships for the future.

This paper will concentrate on the methodology for meeting that last goal.

THE BASIC REQUIREMENT

As already indicated, the prime requirement of the customer is to make a profit. In the present case, the customer of the ship's supplier/builder is the owner or owner/operator of the ship. Where the owner is not also its operator the management of the ship would be handled by a specialist organization responsible for seeing that the requirements are satisfied. It would therefore be useful to state explicitly what the basic need of the customer is, i.e.:

"To be profitable in the selected operation, by employing a ship with the agreed specifications, which at the same time satisfies the demand for cost-effectiveness and an acceptable level of safety."

It is important to understand the implications of this statement. They are that the profitability of a project or operation depends on the use of a ship which meets three separate sets of criteria in equal measure. These relate respectively to specification, cost-effectiveness and
safety. Generally, each set on its own can be readily met. For example, it is possible to build a low-cost ship if the specifications are not demanding and a high level of safety is not called for. The real challenge is to provide a ship that meets demanding specifications, is cost-effective and also incorporates every desirable safety feature.

The problem requires a multi-level and multi-variable optimisation formulation. Its complexity stems from the qualitative and subjective nature of some of the relationships between the variables. To satisfy the requirement, therefore, it is essential to have a suitable methodology.

WHAT CONSTITUTES COST AND SAFETY EFFECTIVENESS?

In order to understand the composite term "cost and safety effectiveness" it would be useful to begin by defining the individual elements.

Cost Effectiveness
There are a number of ways of fulfilling the requirement for any task and each involves a specific cost. Variations in such cost can be wide-ranging, depending on the nature of the task. In the days when the quality of a product was judged by technical criteria alone, the cost of a specific task was a secondary consideration. A good example of this relates to the exploitation of oil and gas in the UK sector of the North Sea in the 1970's. The national goal was to be self-sufficient in oil by 1980 and the solutions adopted were those which had proved successful in the shallow waters of the Gulf of Mexico. "Cost" was a factor well down the agenda. However, with escalating costs and strong competition from alternative solutions, it eventually became necessary to seek value for money or cost-effectiveness. This should not be confused with low cost. It may be right to pay a high amount for an item or service if it will yield the desired level of effectiveness. The most obvious example is the choice between a product at a low capital cost with high running costs and one at a high capital cost but with much lower running costs. The crucial factor is "effectiveness" and the decision on this must be based on both commercial and technical considerations.

Safety Effectiveness
"Safety" is a word frequently used in many different contexts but the users' interpretations can vary widely. They range from the dictionary definition of "avoidance of personal injury" to the commercial one of "not losing
money. Questionnaires circulated to a wide spectrum of technical personnel yielded the following results:

- Practising engineers believe safety is concerned with design and rules and regulations.
- Academics think "reliability studies" and "risk analysis" are most relevant to safety.
- Operators would regard operating procedures as most closely associated with safety.

In the engineering context, "safety" is defined as follows:

"Safety is a perceived quality that determines to what extent the management, engineering and operation of a system is free of danger to life, property and the environment."

There are a number of words in this definition which need clarification:

Quality: Safety is not something absolute but a quality that has to be specified according to given circumstances and can be continuously enhanced over a period of time as a result of increased experience and new situations.

Perceived: Safety is a perceived quality because it depends on actual circumstances and the competence and experience of those involved in the situation.

System: The term "system" is used to represent any complete structure such as a ship or some component of an installation, process or project.

Management: A system is introduced to meet a specific objective which is implemented by the management of the organization. Excessively demanding managerial decisions can greatly affect the level of risk incurred.

Engineering: Many of the factors affecting safety are related to technical factors.

Operation: Operation is important because even the most carefully thought-out system could fail through incorrect operation. It is also
virtually impossible to cater effectively for the interaction of all possibilities, especially in the case of the more complex systems such as ships.

**Life:**
Safety is most closely associated with human life, and that is the right emphasis. In practice, a human being is exposed to many different types of danger in different activities, and it would be impossible to achieve absolute and total safety in this respect.

**Property:**
The term "property" covers both the system of interest and other systems that may be endangered by it in any way.

**Environment:**
Marine failures, and others as well, can affect the environment in a most significant way.

"Safety effectiveness" determines to what extent the requirements relating to safety are satisfied in the best possible way.

**Cost and Safety Effectiveness**
If the cost and safety aspects of a project are combined, then both will be given equal weighting and the two factors can be incorporated simultaneously and at the right level.

**THE CONTRIBUTIONS OF INTERESTED PARTIES**

Three groups who can contribute directly or indirectly to improvements in cost and safety effectiveness are:

**Group A : Customers**
This group can be divided into three subgroups: those who use ships, e.g., passengers; those who work on ships; those who own them. The interests of these subgroups may differ slightly in emphasis but it is their demands that will bring about higher acceptable levels of safety and value for money.

**Group B : Implementers**
The influential people in this group are: ship operators; ship designers and regulators, and the level of cost effectiveness that can be achieved in a specific vessel is determined by their efforts. For example, many significant cost factors are affected by design decisions.
Group C : Supporters
This group includes: suppliers of equipment and materials to shipbuilders, researchers working on ship technology, and the educators who train both naval architects and ship operators. Each of these can indirectly help to determine the extent to which cost and safety effectiveness can be achieved in new ships.

When evolving new ships in the future it will be essential to take into account the views of all these groups.

PROPOSING AN APPROACH

Having outlined the requirement there is a need to have a suitable methodology that can be applied to evolving ships which will have cost and safety effective features. A number of possible approaches have been examined. Typical examples include incorporating cost and safety criteria into the spiral design cycle (Erichsen, 1989) and decision based paradigm (Mistree, 1990). While all these approaches have strong points they also have some drawbacks and it was decided to adopt a methodology which involved the following steps.

STEP 1: Establish the Life Cycle of the Ship
The first step is to identify the phases in the life cycle of the ship after the owner/operator's general specification has been obtained.

STEP 2: Apply PREVENT-IT to Safety
Based on the concept of prevention, the safety methodology called PREVENT-IT is employed to evaluate the safety factor in each phase of the ship's life cycle.

STEP 3: Integrate Cost Criteria
In deriving the desired ship, cost criteria are introduced in each phase of the life-cycle after the application of PREVENT-IT.

Each of these three steps will now be examined in the sections that follow.

THE LIFE-CYCLE OF A SHIP

To enable cost and safety to be taken fully into consideration in the evolution of a ship it is helpful to understand the complete process that begins once the ship owner has outlined the basic requirement. One very flexible way
of representing it is to examine the "life-cycle" of a ship, which can be regarded as comprising eight phases which are summarised as follows:

Concept: The objective of this phase is to prepare a selection of sound possible concepts which would meet the owner's requirements. This will involve tasks ranging from brainstorming sessions through the evaluation of suitable ideas to estimation of approximate costs and the level of safety which can be offered.

Feasibility: The aim here is to establish whether the preferred concept will meet the requirements in the most effective way, so that the owner can decide if the proposed ship is suitable. The alternative name for the phase is "preliminary design". Typical tasks involved are preparing the layout of the ship, calculating estimates of the costs involved, and considering its safety features.

Detailing: The work of this phase should provide all the necessary information for procurement, construction, operation and other relevant purposes. It is sometimes referred to as the "engineering" phase and should yield a complete description of the project and its individual components. This will include the full specification of each part, based on the appropriate code of practice and backed by comprehensive calculations to verify how well the design criteria have been met. The output consists of drawings, material specifications, planning data, procedures, etc. It is also at this stage that details of the resources required are established.

Procurement: The aim is to purchase from the most suitable sources all the materials and equipment for the ship, as defined in the previous stage. This involves building up a list of approved suppliers and negotiating with them for the items that are most suitable from the points of view of price and quality.
Construction: The main aim in this phase is to convert the established details and procured materials into the hardware of a ship, with the greatest possible efficiency. The tasks involved include planning, production processes such as cutting, welding and assembling materials into units, the installing of equipment, the control of progress and outfitting.

Commissioning: The aim is to check that the structure and its equipment will meet the specifications. Acceptance tests and ship trials are performed in this phase and adjustments are made to ensure conditions are satisfied.

Operation: This is the phase in which the ship has to fulfil the customer's requirement of generating income. Tasks involved include familiarising the crew with the running of the ship, close monitoring of performance, maintenance and repairs.

Decommissioning: After the useful life of the ship is completed the aim here is to dismantle it in an environmentally acceptable manner. The tasks involve the systematic downgrading of the functional capabilities of the ship and its eventual breakup.

It will be noted that cost and safety aspects have a role to play in each phase, and their maximum impact in the phase of interest will stem from effective decisions made in the earlier phases.

THE PREVENT-IT SAFETY METHODOLOGY

The safety methodologies most suitable for use in this approach include PREVENT-IT, see (Kuo, 1990). (Note that the term PREVENT-IT is a registered trademark). It consists of the following nine steps:

STEP 1: Predict Potential Hazards
The first step is to predict potential hazards for the concept, design or ship as appropriate. Typical examples of such hazards would be fire, flooding, instability and collision. Techniques
such as HAZOP and HAZAN are applicable. (Kletz, 1986).

STEP 2: Research into Risks
The risk of occurrence should be calculated for each of the hazards identified. Risk is defined as the product of consequence by probability. Typical techniques such as Fault Tree Analysis (FTA) can be used, see (ASTEO, 1987).

STEP 3: Establish the Role of Human Factors
The human factors of interest are management, competence, confidence and communication skill.

STEP 4: Verify the Scope for Design Modifications
On the basis of the previous three steps it may be possible to reduce risks by careful design.

STEP 5: Engineer the Containment Systems
Many factors contribute to the occurrence of a major accident, see for example (Charlton, 1989). However, the introduction of containment systems may well be sufficient to a turn a potential major accident into a minor one.

STEP 6: Nominate Viable Emergency Solutions
Emergency solutions will always be required, no matter how far potential hazards are minimised. Typical solutions in ships include escape routes and lifeboats.

STEP 7: Transmit Quality Requirements
Failures often occur because design details were not correctly fulfilled or procedures were not followed. The management must insist on the highest quality in everything connected with the life-cycle of the ship.

STEP 8: Interface with Regulations
Steps 2 to 7 can be regarded as the "good practice" of any organization. But ships have to satisfy a variety of national and international rules and regulations as well. Proper interface with these must therefore be achieved.

STEP 9: Train the Personnel
To ensure that a high standard of safety is maintained, all personnel must be trained to recognise potentially dangerous situations, to take appropriate action to correct them, and to
provide feedback on experience gained in practical situations.

It will be noted that PREVENT-IT provides a mnemonic of the first letter of the title of each of the nine steps.

INTEGRATING COST WITH SAFETY

Application of the appropriate steps of the PREVENT-IT safety methodology to each of the relevant phases of the life-cycle of a ship makes it possible to reach the required level of safety systematically. The first three steps, for example, can be applied to the concept phase and the first five can be used to study the feasibility phase. It is therefore a matter of direct addition to apply cost criteria at each stage after safety has been considered. This is best illustrated with the aid of an example.

EXAMPLE OF APPLICATION

Any practical application would contain too much detail for this paper, but Appendix 1 provides highlights of the key stages for evolving a cost and safety effective ship for stand-by duties in the North Sea.

DISCUSSION

The following three issues call for brief examination:

Attitudes to Cost and Safety
Those associated with ship technology and ship operation must take a positive attitude to both cost and safety and see them as complementary rather than contradictory. Safer ships need not be more expensive provided the two factors are considered and implemented at an early stage.

Life-Cycle Approach
The whole life-cycle of a ship should be considered when cost and safety are being examined, because the implications of their effectiveness vary in each phase and they must be taken properly into consideration each time.

Role of Education
In the 21st century engineers will need to have a high level of competence, confidence and communication skill in balanced proportions in order to cope with ever-changing demands for cost and safety effective ships. Education has a key role to play here as it will not only help to build
up the right level of technical capability but also ensure that they also have a proper appreciation of business fundamentals at an early stage.

CONCLUSIONS

The main conclusions to be drawn are:

a) A positive attitude must be taken by all concerned with shipbuilding, so as to recognise that it is possible to meet customers' specifications and at the same time be cost effective and have an acceptable level of safety.

b) Ships that are cost and safety effective can be evolved in practice by the application of both cost criteria and the PREVENT-IT safety methodology to every phase of a ship's life-cycle.

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APPENDIX 1: HIGHLIGHTS OF THE COST AND SAFETY EFFECTIVENESS APPROACH

The Customer's Requirement

This can be stated as follows:

"To examine what would be the most suitable ship for the market for standby support duties for an offshore platform in the North Sea. The proposal should give good value for money and meet a high standard of safety."

The Initial Stages of the Approach

The Approaches involves the following key stages:

Stage A: Implement the Concept Phase of the life-cycle by applying the first three steps of PREVENT-IT to a number of possible concepts developed through brain-storming sessions or via the previous experience of those involved. Compare the cost implications of each concept. The decision on the preferred concept will be based on how well it satisfies both the cost and the safety criteria.

Stage B: The Feasibility Phase is implemented by applying the first six steps of PREVENT-IT to the preferred concept. After its safety level has been clarified the preferred concept will be evaluated against cost criteria using either the payback method or the net present value method.

Stage C: The output of the previous stage will allow the customer to decide whether to go ahead with the proposal or to consider fresh concepts to meet amended requirements.

Other Stage of the Approach: When the decision is a negative one Stages A and B are repeated until such time as a positive decision is reached. Following selection of the preferred solution, each of the phases in the life-cycle will be implemented and the relevant steps of PREVENT-IT applied, together with appropriate cost criteria. Thus, Stage D will examine the Detailing Phase, Stage E the Procurement Phase, and so on. It should be noted that some of the phases, for example, the Procurement Phase, have a greater impact on cost while others, such as the Operational Phase, relate more closely with safety. To a large extent the steps implemented in a given phase will depend on the amount of information that is available at that time.
ABSTRACT

The paper presents a brief history of the computer applications in the succeeding stages of the shipbuilding process: design (CAD), engineering (CAE) and production/manufacturing (CAM).

In a step-by-step evolution "CAD-calculation-applications" have been linked to "CAM-Numerical-Controlled Cutting machines" by developing 3D-CAE-modules in between. The result is a practical and flexible system of CAD/CAE/CAM modules. The paper analyses the impact on productivity of the modules in each separate process stage (of interest for subcontractors that only perform this stage) and on the succeeding steps and on the total process.

The goal of the paper is to present a guideline (for anyone contributing to the shipbuilding process) to determine:

- for which of your "core-activities" an investment in CAD, CAE and/or CAM-tools can be earned back by improvement of your productivity or by higher value of your product for clients in succeeding process steps, improving their productivity;

- which of your other activities should be subcontracted to CAD/CAE and/or CAM specialists, whose products improve your productivity.

Concluded is that applying CAD/CAE/CAM has a positive impact on productivity in the pre-production processes. Moreover the use of CAD/CAE/CAM-systems generates more precise product-information, which can have a great impact on productivity (manhours) in the production.

1. INTRODUCTION

Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) are descriptions for a wide range of computer applications that can be used in different stages of the shipbuilding process. Computers are used to make calculations and drawings but also to control flame-cutting machines and welding robots. The first application is generally used in the design-stage, the first step to be recognized in the shipbuilding process, (see figure 1): a CAD-application. Numerical Controlled (NC) flame-cutting machines are used in the preprocessing-stage, a CAM-application, to prepare construction parts, resulting in "building kits" for the production stage.
CAE is the third abbreviation used in this paper, meaning "Computer Aided Engineering", not as commonly used as CAD and CAM. CAE covers applications in the engineering-stage, the important step between design and production. In this stage the overall ship design is detailed to all its construction-parts, components are defined etc. The ship to be build is specified in every detail, usually laid down in construction drawings, detailed arrangements, diagrams, parts lists etc.

Figure 1.
The use of computer applications, combined to a CAD/CAE/CAM-systems, concentrates in the shipbuilding industry on the definition of all "product-information" in the first steps of the process in figure 1. Generally the impact of CAD/CAE/CAM on productivity should be positive, either in the process steps in which the applications are used and/or in the following steps. At least somewhere in the process the investment in "computer tools" should be earned back by a saving in manhours or materials. The main question (for the shipbuilder) is "where to invest in CAD, CAE and/or CAM for the best impact in your particular situation?"

Two extreme situations can be recognised in shipbuilding industry today:

- the larger shipyard, covering all stages of the shipbuilding process, aiming to do as much as possible inhouse to be independent;

- the subcontracting infrastructure, like in the Northern part of the Netherlands, in which highly efficient specialists companies concentrate on their own step in the process, working together in producing ships, organised by shipyards with small staffs and a high level of productivity.

In the first situation the decision to make a considerable investment in an integrated CAD/CAE/CAM-package, can be based on the expected rise in productivity somewhere in the overall process.

In the second situation the specialist-firms can invest in applications if:

A. The impact on their own productivity is good enough;
B. The investment results in a new or better product;
C. The service provided has a recognisable impact on the productivity of their clients.

The best applications score on all points, but usually achieving the first point is enough for a positive decision.

Because usually the degree of utilisation of the application is very high in the specialised firms investment pay back is rapid. This allows the firm to continually improve their systems and thus remain in the forefront of technological developments. This was the basis for the foundation of Centraalstaal BV in the early '70's, as a steel preprocessing specialist investing in the most up to date CAM/NC-flame cutting techniques both autogenous and plasma-cutting. CS uses this investment most efficiently, working in shifts throughout the year, on behalf of as many shipyards as possible.
Other company's in the Cono Industrie Groep follow the same philosophy:

- Numeriek Centrum Groningen BV (NCG) specialises in computer-services and software-development for the shipbuilding industry; specialised services like fairing hull-forms and generating shell-plate-production-information are delivered by NCG for over 50 ships per year. This utilisation enables the investment in the development of optimal and practical CAM-software for inhouse production preparation; the delivery of software modules to clients enlarged the scale of utilisation and the possibilities to invest in new developments of CAE and CAM-applications, leading to the CAE/CAM-package NUPAS: NUMeric Production Automation Systems;

- Engineering Centrum Groningen BV specialise in constructional and mechanical engineering for ships, delivered to shipyards; ECG uses NUPAS-CONTEK, a dedicated CAE-system to define the ship-construction, developed in 1988 in close cooperation with NCG, originally for inhouse use but now sold within NCG's NUPAS; NUPAS-CONTEK is an example of a CAE-application with a great impact on productivity in the (engineering) process itself.

The infrastructure of subcontracting specialists required a very flexible, modular system of computer applications. The modules need to have a positive impact in the separate stages of the specialists and on the overall process even if some stages are being performed in the conventional (manual) way. This led to the NUPAS system.

The continuous development and improvement of CAD/CAE/CAM systems requires decisions for every stage of the process in a company: where to invest in systems and specialism or where to subcontract to system specialists.

This paper aims to put forward criteria and information that can be of help in making a choice, starting with a brief history of the step-by-step evolution of modules and systems.

2. DEVELOPMENT STARTING AT CAD AND CAM SEPARATELY

Computer application in the design-step started with calculation programs, such as hydrostatic calculations. Using CAD-modules allowed savings in time for calculations. Besides improving productivity it is more important that the designer can analyse more alternative design options in less time. Optimising the design can have a great impact on the quality of the resulting ship and (generally) on the productivity in the building process. Today CAD-modules are available for practically all design calculations and for parts of the design-drawings, like the lines plan. This "design-hullform-definition" is the most important information that is transferred to the next process steps.
The development of computer applications in the production started at the Numerical controlled flame cutting process. NC-cutting machines required huge investment. Centraalstaal was founded in the early 70's, in order to centralise the steel-preprocessing in one firm acting as subcontractor to several yards. The NC-cutting required the development of computer applications in the earlier process steps, to prepare the computer-production-data for the cutting-machines. A production-hullform-database is needed, to be generated out of the design-linesplan with a computer aided fairing module. This is coupled to modules for the definition of expanded shell-plates, generating production-data for the NC-cutting and forming machines. Based on experience in this process over 15 years, modules have been developed by Numeriek Centrum Groningen, evolving to a complete set of coupled modules for CAM-preparation: NUPAS.

3. CAE: THE LINK BETWEEN CAD AND CAM, KEY TO NUPAS

Engineering is the step in between design, where the overall definition of the product 'ship' is defined, and production preparation, where every single construction part or component is detailed. Engineering is the process of calculating and drawing diagrams, lay-outs, approval plans, production drawings, etc. A great deal of shipbuilding engineering work is laid down in construction-drawings for every hull section to be built.

The development of computer applications for generating construction-drawings, CAE, started at the end of the 80's at Engineering Centrum Groningen and Numeriek Centrum Groningen. From the start the main goal was set as the linking of CAE to CAM-applications of NCG. It was decided however to take a step by step approach, starting with an application for 2-dimensional construction drawings, staying as close as possible to the proven working methods. In this way the CONTEK-module was developed, a practical and efficient tool, easy to learn within 1 week for an experienced shipbuilding engineer. Ship-construction is generated in an interactive way, by defining construction parts, instead of simply drawing lines. The engineer indicates a command on a (screen- or tablet) menu, the system asks for information about position and measures and generates the construction on the screen. Because the system is linked to the 3-dimensional production-hullform-database of NCG's NUPAS, the shape in the drawing is 100% exact.

As engineering specialist, ECG needed a system with impact on the productivity in this engineering step. With NUPAS-CONTEK savings in manhours up to 40 % are reached, in the production of construction drawings, due to the practical, user friendly approach, dedicated to this specialism. The result however is still 2D drawings, plotted on paper, having not much extra impact on the productivity in the next process steps.
The next step was the realisation of NUPAS 3D, to link CAE and CAM. With NUPAS 3D NCG choose the approach of working with a product or production model of the ship completely 3D and solid. Different from other systems it is not necessary to build the model in the computer and subtract the drawings from it: NUPAS 3D works the other way round.

With NUPAS 3D you work as an engineer, using mostly the same commands as in the 2D system. The construction is generated in views and cross sections and the system builds the 3D model automatically: the status of the model is the status of the engineered construction. With this approach it is feasible to use CAE/CAM in a time-critical environment as in medium and small shipyards, where engineering, work preparation and production are more parallel as sequential activities. The resulting 3D "product-model" contains solid production-info of the construction parts, directly available for the CAM-system, the nesting and CNC-cutting modules.

4. THE IMPACT OF NUPAS-3D

3D-CAE has a positive impact on engineering:

- construction parts are only once defined in the product model, they appear in all 3 projections in the drawings;
- construction is consistent this way, resulting in better quality information;
- production-data is automatically generated, directly in the step where construction is defined by the engineer: production data is always consistent with engineering data.

The use of 3D-CAE does not result in a great saving in engineering-manhours (compared to using the efficient NUPAS-CONTEK 2D CAE). The resulting product however is of greater value for the next process stage: it is computer info, readable input for the CAM-modules on floppy, tape or direct data exchange, instead of the conventional 2D drawings.

The 3D product model of the hull construction is an excellent basis for 3D piping systems, with which the engine-room systems can be defined. An existing piping CAD/CAM-system, that has proven its value in the petrochemical industry, is adapted for use in the shipbuilding industry, and is being linked to the NUPAS 3D product model. With the resulting system, the ship to be built can be defined completely in the engineering stage in to its construction parts: plates, profiles, pipes, appendages and components.

The impact of the 3D CAE on the work preparation and pre-processing steps is of greater importance: the laborious coding of construction parts out of 2D drawings can be eliminated!
The preparation step now concentrates on the determination of the machines to be used and of the necessary input data, using the available CAM-modules. This can be nesting of plate-parts in steelplates for DNC-cutting machines, automatic nesting of profiles for a DNC-profile-bending machine and (in future) generating data for DNC-pipebending machines.

As long as robots are not commonly used in the production of hull sections, system units or hull assembly, there is no direct computer data transfer to Numerical Controlled machines in those production processes. Still the impact on productivity of using 3D CAE can be the greatest of all; having a complete 3D computer-definition of construction, piping and components enables to obtain maximum advantages of 100% pre-outfitting of sections.

Also every hole for any pipe to be cut in construction parts can be known before the pre-processing stage. Manual flame-cutting in hull construction parts during assembly and outfitting stages could theoretically be avoided: the technical conditions are realised.

The NUPAS 3D CAE module is the key to the effective linking of CAD-modules to CAM-modules, each with their own impact on productivity in the separate process steps and together on the "pre-production-processes" as a whole system. Each firm contributing to any stage in the shipbuilding process should determine for which processes it wants to be in the forefront of technological development.

5. CAD, CAE, CAM: where to invest? Where to subcontract?

New technology leads to a continuous development of computer-applications, aiming at new and more efficient working methods; there is a growing positive impact of the aid of computer tools on the various process steps. For every company contributing to the shipbuilding process the moment comes to join the "computer aided wave" and take advantage of the available systems. At that moment questions have to be answered:

- Which system should be chosen?
- What modules for which processes to start with?
- How to learn and grow step by step?
- What "input" do I get from suppliers, what "output" should I deliver to my clients?
- For which process steps can the CAD/CAE/CAM-modules be used most frequently and where will the impact be most attractive (the "core-activities")?
- Which process steps can be subcontracted at a CAD/CAE/CAM-specialist whose output can be used in one's own system?
The last points are determined by criteria like:

- the extend of the investment for tools for a special application compared with the frequency they can be used;
- the degree of specialisation needed for optimal use of the tools;
- company's policy and strategy concerning independence versus co-maker relations;
- possibility to subcontract at the desired system and level of cost and quality.

With a system as modular and flexible as the NUPAS-system of Numeriek Centrum Groningen there is the possibility to determine the optimal set of modules for each company in shipbuilding industry.

A start can be made with the modules for every single process step, because conventional "hand-made" input can be handled, conventionally like output can be generated and/or every process step can be subcontracted at several specialised service-suppliers using the NUPAS-system, for instance at Engineering Centrum Groningen.

In general the decision to invest or to sub-contract is determined by the frequency with which the CAD/CAE/CAM tools can be used, as this influences the pay-back-period to a large extend. In ship design, the CAD-tools for calculations for every project to be offered are used very frequently, so investment is quickly recovered. Highly specialised design-calculations for some of the few projects that become contracts, can be subcontracted, for instance at MARIN in Wageningen.

In engineering, the CAE-modules can be used to reduce manhours in the (former) drawing and/or work preparation-departments. The workload in this department depends on the complexity and the number of new designs to be engineered in a year. For shipyards building series of vessels the demand for engineering can be very different in time and subcontracting of engineering parts at a CAE specialist is most efficient. When building complex "one-off" vessels, having a large engineering department, investing in CAE can be attractive, to reduce manhours, speed up the pre-production phase and improve the completeness and quality of the engineering output.

For CAM-modules the question to invest or to subcontract is even more depending on the specific situation of a company. CAM-tools for the production fairing and generation of expanded NC-shell plate info are mostly used by specialised subcontractors like Numeriek Centrum Groningen, for over 50 ships per year. Activities like nesting, generation of parts lists and Numerical Controlled cutting of construction parts can be done at shipyards or at sub-contractors like Centraalstaal in a co-maker-relationship.
As the investment in CAM-tools and NC-cutting equipment is rather high, they should be used constantly for the most efficient situation. This can be more easily achieved by a subcontractor working for different yards, than at a shipyard working for its own production only. On the other hand yards do invest in CAM themselves, for reasons of independency and because of the already available equipment and departments, still improving their productivity. In this situation a step by step program for the implementation of CAM-modules gives best results.

6. CONCLUSIONS AND RECOMMENDATIONS

The general conclusion can be that the positive impact of the application of CAD-, CAE and CAM-tools on productivity, differs per system and per company, depending on:

- the steps of the shipbuilding process in which the company is involved;
- the company's policy in subcontracting or independency;
- the specific qualities and flexibility of the system.

As we define productivity as the ratio between "output" and "effort", this positive impact can be recognised in 3 ways:

1. a saving in manhours (effort) in a specific process step in which the CAD/CAE/CAM-tool is applied;
2. a higher quality and added value of the product, service and/or information (output) resulting from that step, enabling to use CAE/CAM-tools in the next process steps to reach an optimal saving in effort in the overall process in shipbuilding;
3. a saving in effort and manhours in the production process because of the better quality of the resulting output of the pre-production process; exact NC-cutting enables better fitting construction parts and because of this, constructions can be designed that are easier to assemble, saving manhours in production.

To determine the optimal system for a certain company, achieving the greatest overall positive impact, we have to analyse:

1. the present process steps in which it is involved;
2. for every process step:
   - which of the above mentioned impacts can be achieved by which investment in CAD-, CAE- or CAM-modules;
   - which input should be handled, which output should be generated (also manual/conventional, etc.).
- what investment is needed compared with the degree of utilisation of the tools;
- what is the extra added value of the output;

3. for the company's overall process:
- what can be the total overall impact if CAD-, CAE- and CAM-modules will be applied in all steps;
- which steps can more efficiently be subcontracted at a specialist using the right system-modules;
- which flexibility is needed to handle conventional input;

4. the optimal sequence in which the system modules should be implemented in the running processes.

To determine optimal systems for different companies requires a flexible and complete modular system:
- separate modules have to be especially tuned to the specialism of the process steps for which they are developed, to get a maximal impact per step;
- every module should be flexible in input and output, the greatest impact will be achieved with input from modules of the same system, but also conventional/manual input should be handled in an efficient way;
- time critical situations should be taken in account.

These are the principles for the continuous development of the NUPAS CAE/CAM-system of Numeriek Centrum Groningen, aiming at maximum impact on the productivity of the specialists in the company's departments or at subcontractors. The greatest impact can be achieved by coupling the specialism of CAD and CAM with the NUPAS CAE-3D-productmodel: "1 + 1 + 1 = 5"

Recommendation:

In the continuous struggle for better efficiency, every company should analyse its own processes and determine which process steps are assigned as "core-activities" to invest for in the CAD/CAE/CAM-tools of tomorrow. For the other process steps the gain in efficiency by subcontracting at a specialist/co-maker will become more important than being able to do everything inhouse.

We see a lot of challenge for the future and we are confident to give answers to a lot of unanswered demands.
Development of one side submerged arc welding of plate panels and hull sections in shipbuilding

Th.J. Mathu, J. Vuik

1 ABSTRACT

In West Europe, shipbuilding has been characterized for a long time by experience, good workmanship and qualitative excellent ships, rather than by advanced production techniques. In the last decade, this absence of advanced production techniques has been changed by the introduction of the so-called panel-lines. Some of these panel-lines include a one side welding station for the production of long, wide plate panels from relatively small rolled plates. Authors will describe how social aspects and technical capabilities have initiated the development of the one side submerged arc welding of double walled hull structures and box shaped girders. This technique uses the high penetration of the submerged arc welding process to join the stiffener and the plate panel from the outside of the construction. Essential in this technique is the system used for supporting the liquid weld metal, and the process tolerances in the welding parameters in relation to fit-up, positioning and bevel shape of the joint.

This production technique is only one aspect in a totally new concept for designing and building ships. The basic philosophy behind this concept is briefly explained in this paper.

2 HISTORICAL BACKGROUND

The design of ships, whose outer skin consisted of large more or less flat plate panels, has led to a continuous development in the production procedures to lower the required amount of manhours per ton steel weight.

Conventionally, plate panels are welded using the two run submerged arc process (in a lot of shipyards better known as the Union Melt process). This submerged arc process is characterized by a high penetration and deposition rate and for a shipyard perhaps also important: a high process reliability. The latter means that the process is not or little susceptible to all kinds of problems coming from the equipment used and skills of the operators.
By using this two run S(ubmerged) A(rc) process, the plate thicknesses currently used in shipbuilding (approx. 6 to 20 mm) can be welded quite conveniently. The welding speed is high: optimum penetration is achieved with welding speeds of 50 cm/min and above. The only weak point in the two run SA technique, is that after having welded all seams on one side of the plate panel, the entire panel has to be turned for backgouging and/or backwelding.

This turning operation requires
- a production hall with enough height, to turn the platefield with large dimensions,
- large crane capacity, and special lifting equipment to handle unstiffened platefields,
- skilful crane drivers, which often have to work in pairs in close cooperation,
- patience when waiting for the available special hoisting and turning tools, for the turning operation (by the panel fabricator).

In addition, this turning is known to be not free from danger. It has occurred, that when turning the panel, with SA welds on one side, cracking of one of the welds led to dangerous (collapsing platefields) situations.

It was for the reasons mentioned above, that in the seventies some yards renewed their involvement in the one sided SA welding of plate panels.

3 PANEL LINES, INCLUDING ONE SIDED SA WELDING OF THE PLATE PANELS.

The design of ships, consisting of a lot of (more or less comparable) plate panels, either single or double walled, made it interesting for shipyards to standardize the production methods of these panels.

The basic step is to put all necessary equipment in line, and to built the panel on a production floor, that makes it possible to "feed" (transport) the panel along all production equipment.

Before dealing with the production of a plate panel, with dimensions of e.g. 12x25 m, the general outline of such a panelline has to be indicated.
First of all, the bulbs (plate stiffeners) are positioned and tack welded. Then they are welded to the plate, using a double sided MIG/MAG or SA device.
Over these bulbs, the webs (longitudinally and transverse stiffeners) are positioned, and welded by hand with stick electrodes or MIG/MAG.
After having completed, cleaned and inspected all welds that can be welded before the tanktop is placed, the welds and their adjacent Heat Affected Zone are locally covered with a shop primer.

After having positioned the tanktop, it is manually tack welded to the webs in the overhead position, and then the boxtype module can be turned to make down-hand welding procedures possible.

Composing the flat plate with dimensions of e.g. 12x25 m can be done by means of the two run SA technique, as mentioned before. However, some shipyards have already invested in a one side SA equipment for joining plates to the required dimensions. The basic principle is drawn in Figure 1, and consists of a SA machine, and something to support the liquid weld metal.

The SA process is used for its high penetration, and the use of the weld pool support material is obvious.

Of course, there is needed some device for positioning and clamping the plates. And it is this rather basic necessity, that determines to a great extent the quality of the weld of a one sided SA station.

For supporting the liquid weld pool, several systems can be used. In principle, one could simply use a copper strip as a backing material, just as is done in one side welding of aluminium. However, the risk of copper pick-up is very great with the high penetration and heat input of the SA process. Because of the problems that arise then, this copper backing is not recommended.

Two systems that are frequently used are a woven glassfiber tape, and a special encased flux layers, both supported by a liquid cooled copper bar. This copper bar is pressing the backing material onto the back side of the plates to be welded. In some cases this copper weldpool supporting system is designed as a flexible plate line following system (spring loaded).

With this system, one sided welds can be produced in plates with a thickness up till approx. 15 mm in one pass or up to 25 mm in multiple pass execution.
4 BOXTYPE GIRDERS AND THE ONE SIDED CLOSING PRINCIPLES

4.1 General:

When producing platepanels with one side welding of butts, one easily gets the inclination to extend this principle towards the fabrication of one sided closed boxtype girders. These girders have a more and more widespread field of application in modern shipbuilding and in general utility steel construction works. Examples are: double bottom tanks, side tanks, floating cases, blistertanks, cofferdams, double deck constructions, rudders, propeller nozzles in shipbuilding and the construction of platforms, cargodecks, loadingbridges, dockdoors, doublewalled cargotanks and other types of secondary isolation barriers for continuous or emergency purposes, etc.

The solution for the production of such type of constructions is nowadays mostly found in the use of slot-welds or plate-edge welding on permanently applied steel backingstrips and where possible by means of manual (mostly in position) backwelding from the inside of the enclosed constructions.

The new concurring insights in the required and preferred labour conditions makes the present working attitude questionable in the longer run. Besides there is a strong international trend and legislation to the prohibition of human labour to be executed in such enclosed environment, without the use of extensive personal protection devices such as facial breathing masks.

Such equipment is in this application most unpleasant for the bearer and not ergonomically justified.

For solving or avoiding this problem a huge change in attitude of both the designer and user of boxtype products are necessary.

4.2 The new approach of boxgirder design and production:

A. Starting points for the conceptual approach of the design:
1. To create a universal applicable solution for the modular design of boxgirders, primary doublebottom units of ships.
2. To conceive a construction fit for mechanised or automated welding by dedicated automation or robotics.
3. To supply a design, fit for manufacturing under acceptable labour-ergonomical and environmental conditions.
B. Designers options to fill in this principles:
To cope with these contradictory demands the designers came with the following approach:
In close cooperation with the classification societies, it must be possible to create a separation in the basic functions of the product, which can lead to a different way of production.
This means one part of the construction accounts mainly for the absorption of the external loads, including the overall longitudinal loads and the other part takes care of the (cargo)loads from the insides of the construction.
This means two basic load situations:

B1 bottomside:
- the external waterpressure and local dockingforces, etc
- the longitudinal bending forces from the integrated unit or product in its final application (e.g. wavebending forces).

B2 topside:
- the internal forces on the tanktop by cargo inside of the compartment or applied from the top by cargo or incidental loading-equipment (e.g. forklift trucks).

Target of the designers:
To combine these two segregated principles to one integral design for a boxconstruction.
Several discussions were held to find a basic designprinciple which could be approved by a Classification Society.
One of the disputed points was the idea to deliberately withdraw the tanktop panel and its internal stiffeners from the influence of the longitudinal strength. For proving the principle basic finite-element calculations of different stiffener-end constructions were executed.

C. Additional design principles to be accounted for:
1 Each unit to be assembled from the lowest amount of parts as practical possible.
   This means as much as possible flanging of plate elements, or use of commercial available standard profiles.
2 The unit must be constructed in such a way that it can be welded for the major part by mechanised welding.
3 During production the need for three dimensional manipulation of the boxgirder from the
welding point of view, should be avoided as much as practical possible.

4 It must be clear that inside welding of the enclosed construction is not allowed anymore and therefore to be avoided from the design point of view. This means that all the internal welding must be executed in "the open situation" and the "lid" must be welded to the internals from the outside.

D Production tests in laboratory to simulate workshop conditions

Special tests were executed with one side welding by means of the submerged arc process. The advantage of pulsed SAW was investigated to obtain a controlled penetration with a meltpool as small as possible.

Additional tests were executed with different types of meltpool supports and different combinations of material thickness both in horizontal (tanktop) and in vertical plates (webplate).

The results are promising, but a long way still has to be followed before a practical acceptable solution is reached.

One of the major problems to be solved, is to develop a sensor system capable of determining the actual position of the members to be joined underneath the tanktop-panel. Several principles are studied in a pre-investigation program, but no actual tests have been executed yet.

We believe that it is essential, both for shipbuilders and for mechanical engineers to join us in this development in order to cope with the human- and legislative demands of the coming era in steelconstructions.

Both authors, Mathu and Vuik from TNO Industrial Research, invite you to share your ideas with us, to define a good solution for the mentioned problems and to take care of a good humane working environment for our esteemed working force in the future of shipbuilding and steelconstruction.
TTS One Side Buttwelding Station

"TTS glassfibre backing/CO₂/Sub.arc" welding method

1. Upper clamping beams
2. Lower clamping beams
3. Welding tractor running beam
4. Sub. arc welding tractor
5. Inspection pit

"Flux covered backing" welding method

1. Upper clamping beams
2. Lower clamping beams
3. Welding tractor

Fig. 1
Monitoring and control of automatic welding
R. Fenn, S.M. Cannon

SUMMARY.

In large fabrications subject to complex stressing in service (e.g. ships), the existence of planar defects in welds could prove disastrous. Defects such as lack of penetration, interrun fusion and cracks must be avoided. Prior knowledge of the size and location of these defects are essential if predictions on fatigue crack initiation and propagation lives are to be determined. Relatively simple techniques used to predict reductions in life show the importance of detecting defects during manufacture.

Ultrasonic monitoring of the weld pool has been demonstrated and has been used to control the arc welding current and thus penetration. This task utilises the 100% sound pressure region of a divergent transverse wave ultrasound beam. Control is via a fully closed loop using a computer to monitor U.S. signals and to adjust the welding current. This technique has resulted in penetration control accuracies of +/- 0.3mm in plates greater than 10mm thick. A wide range of materials have been employed, as have an equally wide range of welding processes. These systematic studies have shown that the accuracy of the results remain unaffected.

Ultrasound beam spread creates the conditions where the leading edge signal interrogates the weld seam immediately in front of the weld pool whilst the trailing edge signal examines the freshly solidified weld metal. Both of these signals have been utilised. Seam tracking has been demonstrated to accuracies of +/- 0.3mm (about the same as the reproducibility of an industrial robot), whilst work on defect identification is still on going. Currently both planar and porosity defects can be identified in real time at about the 1mm size.

A simple reference system, comprising of welding code and acceptable defects will be programmed into the control computer. This will enable the system to decide whether to continue welding, or to stop, if it detects solidification defects.

INTRODUCTION.

The concept of in-process inspection and monitoring has been addressed as the act of interrogating and characterising weldments during the weld cycle. When a control system measures the workpiece and uses the measurement information to compare and correct in line with design data this is termed "in-process". In-process controls rely on the sensing of variables directly at the point of welding. Very few other production processes permit such in-process control.
Automatic process control and rapid inspection techniques must be used to keep production errors from generating large numbers of faulty products. Welds must be inspected along the joint to be sure that welding defects will not weaken the final product. Ultrasonic methods are the most promising of the possible non-destructive evaluation techniques for these inspections because they can interrogate internal structures at production line speeds.

One of the most important characteristics of a fusion weld is that it should show complete and uniform penetration\(^{(1)}\). Lack of root or side penetration can either statically or dynamically result in failure due to the formation of notch-like defects becoming the site for crack propagation. Due to the high cost of downtime and destructive testing, many welded structures are not inspected as often as they should be. For an efficient application of the methods of weld quality and in-process control in welding, it is necessary to develop sensors providing accurate information of the condition of the weld, especially data on the depth of undercut, the extent of penetration, the height and shape of the underbead of the weld, the structure of the weld metal, and other parameters of weld quality. Such a system of sensors combined with controlling computers ensures the formation of welded joints with the required geometrical characteristics and service properties\(^{(2)}\).

Workpieces that have flaws in them present two major problems for industry. The first, of course is the existence of the flaw itself, how it was created and the potential adverse effect on the finished product. The second part of the problem is detecting the flaw on a production basis and qualifying it accurately. Typically, skilled inspectors are used to check workpieces periodically, comparing them with masters that exhibit acceptable or rejectable flaws. This type of quality control is usually very expensive and inconsistent to some degree since it is dependant upon personal option. Fatigue, boredom, human error, or borderline decisions all take their toll on the accuracy during the workday. In answer to these problems, the paper presented will firstly evaluate the effect of defects on the fatigue life of a structure and then introduce a flaw detection system which automatically performs consistent high speed, high accuracy inspection of defects through the use of ultrasonic transducers.

**EFFECT OF DEFECTS ON FATIGUE.**

Welding has been commonly used in the joining of ships for several decades and it has been stated that the weldment constitutes ca. 1% of the total mass of the ship. Thus it is reasonable to assume that a number of weld defects will be present within the structure. Rogerson\(^{(3)}\) investigated the occurrence of defects within ship hulls and reported their population in comparison with other major welded constructions. His results, shown in table 1, reveal that the hulls contain about 4.9 defects per metre of weldment. These defects can be categorised into a number of groups, viz a) cracks b) cavities (porosity and shrinkage) c) solid inclusion (slag and oxides) d)
lack of penetration and fusion e) imperfect shape and f) miscellaneous (eg spatter, arc strikes etc.) 

Table 1: Defects in welded constructions (after Rogerson)

<table>
<thead>
<tr>
<th>Structure Type</th>
<th>Average number of defects per metre of weld</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium pressure Vessel (MIG welded)</td>
<td>1.6</td>
</tr>
<tr>
<td>Steel site welded Tankage (MMA Welded)</td>
<td>0.7 - 4.9</td>
</tr>
<tr>
<td>Steel site welded Tankage (Sub arc welded)</td>
<td>3.4</td>
</tr>
<tr>
<td>Ships hulls (MMA welded)</td>
<td>4.9</td>
</tr>
<tr>
<td>Low alloy steel pressure vessel (MMA welded)</td>
<td>0.7 - 1.0</td>
</tr>
<tr>
<td>Low alloy steel pressure vessel (Sub arc welded)</td>
<td>0.3 - 0.5</td>
</tr>
<tr>
<td>Nodes in tubular offshore platform jacket (MMA welded)</td>
<td>5.9</td>
</tr>
</tbody>
</table>

The technique for welding presented in this paper describes a method for controlling weld penetration. Lack of penetration is usually considered as a planar defect and its importance needs to be explained briefly to validate the welding technology research.

A ship, such as a large bulk carrier, may be described as a flexible beam which operates in a seaway. The seaway itself is of a sufficient nature to excite resonance within the structure. These low frequency loads are the main driving force behind the global fluctuating stresses which cause fatigue cracks to grow within the main hull girder.

Fatigue failures consist of three distinct phases. Firstly there is the initiation, followed by propagation until the crack reaches a critical length before brittle or ductile failure occurs. In welded constructions, however, it has been shown that the neglect of the time for the initiation period has little effect on the total failure time. Thus it is sufficient to consider only the fatigue crack propagation period. Experimental work on the effect of lack of penetration on fatigue life has been available for several years. Alternatively simple models may be used to quantify the reduction in fatigue life. One such approach based upon fracture mechanics is outlined below.

Assuming the fatigue crack growth rate is given by

\[
\frac{da}{dN} = B(\Delta K - \Delta K_{th})^2
\]

where \(B\) is a material constant related to the tensile properties and the cracking mechanism present. For specific applications
this equation can be given in the form

\[
\frac{da}{dN} = 3.75 \times 10^{-10} (\Delta K - 7.4 (1-R))^2 \quad \text{for } R \leq 0.6
\]

(2)

where \( R \) is the stress ratio.

The stress intensity factor \( \Delta K \) is given by

\[
\Delta K = F_s F_e F_\infty F_g \Delta \sigma \sqrt{\pi a}
\]

(3)

where \( \Delta \sigma \) is the nominal stress range

\( F_s \), accounts for the free front range

\( F_e \), for the elliptical crack shape

\( F_\infty \), for the finite width

\( F_g \), for the stress gradient due to stress concentration.

Various relationships may be found for these within the open literature(10).

Simple integration of equation 2 can be used to calculate the numbers of cycles to failure. The limits being the initial defect length and the critical crack length to avoid yielding or to brittle fracture. For the purpose of our calculations it is sufficient to assume that the crack may grow until the stress on the remaining ligament is equal to the ultimate tensile strength of the material, i.e.

\[
a_{cr} = \frac{t(\sigma_{uts} - \sigma)}{\sigma_{uts}}
\]

(4)

For the sake of illustration, a typical situation is considered. If a nominal tensile stress across a weld is 100 MPa and a fluctuating stress of 80 MPa. The material properties are assumed to be of an equivalent to LR grade A and has a thickness of 15mm. By varying the allowable crack size and integrating equation 2 the following fatigue lives were obtained.

Table 2 : Fatigue crack propagation lives.

<table>
<thead>
<tr>
<th>Initial Defect Depth (mm)</th>
<th>Remaining Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>3.996 x 10^6</td>
</tr>
<tr>
<td>0.5</td>
<td>2.302 x 10^6</td>
</tr>
<tr>
<td>1.0</td>
<td>1.113 x 10^6</td>
</tr>
<tr>
<td>2.0</td>
<td>5.687 x 10^5</td>
</tr>
<tr>
<td>3.0</td>
<td>3.996 x 10^5</td>
</tr>
<tr>
<td>4.0</td>
<td>3.140 x 10^5</td>
</tr>
</tbody>
</table>

Thus significant improvements in the fatigue propagation lives can be achieved provided the lack of penetration can be controlled or reduced to low levels.
ULTRASONIC INSPECTION.

The purpose of an inspection system is to detect defects in products to maintain established quality levels in them. Inspection of product quality for defects both in manufacturing and in-service, is an important, common and general requirement. Human inspection is, to a large and increasing extent, being replaced by automatic instrumental methods. Fully automatic methods have important advantages as outlined below:

1) Automatic methods have great potential for consistency, while the performance of the human operator is variable with respect to both recognition and judgement.
2) The speed of the human operator is limited and his capability is inadequate for many applications, while automatic inspection methods are potentially capable of very high speeds.
3) Many inspection tasks are highly monotonous while demanding continuous high concentration. Such tasks are prime candidates for automation.

The main tasks of ultrasonic inspection are:

a) Reliable detection of all defects with a large safety margin to relevance.
b) Location and classification, whether further analysis is necessary.
c) Sizing and characterisation of these defects.

These criteria and characterisation are valid for manual as well as mechanical ultrasonic inspections. It is a testing system that does not involve potential health hazards and work disruption. Weld inspection may be divided broadly into two classes:

a) Inspection for the purpose of ensuring that products comply with given specifications.
b) Inspection on a fitness-for-service basis.

The goal is effective process control for economy, for failure prevention and for operational safety of the finished product. It should be emphasised that inspection is concerned not only with the test welds but also with the materials that they represent and intelligent inspection can help enormously in mundane production routines if its energy is directed more towards the fabricated components rather than languishing over post-mortems on test-pieces. Certainly, if it were possible commercially to apply a single NDT technique conclusively to a production weld to prevent failure in service, there would be no need at all for much of the testing and certification done at present. Even so, some failures are inevitable owing to operational causes or inadequate design. The tragedy is that many service failures bear no relationship to the quality of the welder's test, hence the latitude which should be allowed in their assessment is quite different from that accorded to actual production work.
The ideal control of weld quality is to perform such control functions whilst welding. With the present "state of the art" in measurement and control, certain combinations of the parameters create conditions which raise the question "can in-process measurement ever be applied?". Control applied to a manually controlled inspection is relatively simple. The welding operations can be stopped and the operator can use the conventional flaw detector equipment to inspect the weldment. With the particular large volume fabrication, measurement during the welding cycle can be difficult. However, the benefits which can be achieved if measurements can be made automatically during the welding cycle are considerable and would be well worth any investment in equipment. The last two decades have seen enormous changes in both manufacturing and inspection technology. These developments can fulfil four-fold requirements for inspection, viz.

1) improved ease and speed of measurement
2) improved accuracy of measurement
3) reduction in the time taken to record results
4) reduction in the time taken to analyse results

The principal contributory factor in the inspection has been the development of two orthogonal linear tables carrying the probes with motorised drives. This leads to the computer assisted inspection and thence to automatic co-ordinated inspection.

Development of automation of technological processes and development of inspection methods influence and compliment each other thus becoming an integral part of automated production.

Techniques using ultrasonic waves for the detection of defects in materials are now well established in industry and have proved themselves invaluable assets in both production and laboratory. Ultrasonic flaw detection is particularly successful in the metallurgical industries where it is used for the inspection of semi-fabricated products and many finished metal components. In most cases in the past all that has been expected of ultrasonic inspection has been the detection and location of defects, but more detailed descriptions of discovered faults are increasingly demanded as engineering design advances to cope with greater speed and power. In many industries today safety factors are such that even small flaws in highly stressed components can cause catastrophic failure. Obvious examples are to be found in aircraft, ships, atomic energy equipment and turbines, where extreme care must be taken to prevent such failure.

Designers would naturally prefer to have no defects in their materials, but in the general run of production it is difficult to produce metals completely from defects or discontinuities. The problem of inspection therefore becomes one of deciding which defects or discontinuities will have an effect on the behaviour of the material in service. Before this can be done it is necessary to have information not only about their location but also their size, shape, type and orientation. Defects which are large compared with the cross-section of the ultrasonic beam...
present little difficulty since their boundaries can be traced out to determine size and orientation. Furthermore, with the critical type of work mentioned, defects of such magnitude will usually cause rejection of the material. When it is required to obtain information other than location, it is the small defects which present problems and the principal method at present in use is one where a pulse-echo technique is employed. In this technique the amplitude of the echo from the defect is compared with that from a standard known defect. The cost of locating and preparing these defects constitutes a significant portion of the total weld fabrication costs. The welding process is capital intensive, prone to quality control difficulties and unpleasant for human operators.

The current work in-process weld monitoring and adaptive control forms the basis for intelligent welding systems. An expert data base using information acquired will make intelligent decisions concerning process control without human intervention. Two major areas are addressed. Firstly, the ability to select the correct solution to a welding problem must be developed. That is, the sensors must not only be able to detect an out of limits event, the expert system must also be able to diagnose the cause and correct the situation, or determine that human operator must be alerted. Secondly, a fitness for purpose criterion must be included. Thus, when a potentially defective length of weld is formed, the significance of the defect may be assessed based upon the ultimate service conditions so that an appropriate reaction (continue welding, record defect location, stop welding etc.) occurs. Utilisation of machine intelligence (expert systems) is feasible because of the ultrasonic sensors which form a computer cognition system.

THE ULTRASONIC SYSTEM.

A conceptual model of an ultrasonic system to monitor the formation of the weld pool, was constructed in 1979 and was attempted with manual arc welding[11]. It was shown possible to determine both penetration and weld symmetry, the programme was thus extended. Submerged arc welding was investigated on plates of >10mm thickness. Two ultrasonic probes were carried by the welding head to ensure that the relationship between them and the weld pool did not vary (see figure 1). In submerged arc welding the occurrence of maximum penetration lags the centre-line position of the electrode (by about 1-2 mm) and the beam centre-line has to reflect the point of maximum penetration[12]. Equally, due to the heat-flow considerations, the US transducers remain cool as, by the time the heat reaches the probe location, the welding heat has moved forward, as have the transducers. Thus, the sensors are always in contact with cold/cool plate material.

With this approach a series of reference lines was established which, later, simplified the task of automating the welding process and making it responsive to the measurement from the ultrasonic transducers. Control of the weld pool size was exercised by direct control of the welding current (this is because the weld electrode melting rates is controlled by the
forth power of the welding current \( I' \), also this was immediately accessible for control purposes. Even, as crude as the initial system was, weld penetration was controlled to +/- 0.5mm on a regular and reproducible basis (see figure 2).

Figure 3 shows a schematic diagram of the arrangement as well as the control algorithm utilised. From this figure it may also be seen that the natural beam spread covers the whole of the weld zone. This phenomena has been utilised to control the weld pool position relative to the seam and to interrogate the solidifying weld metal (these functions will be discussed later). Lack of penetration accuracies in the weld zone triggered a maximum surge response from the power source which increased the size of the weld pool in all directions and frequently re-melting the area which caused the response.

The above behaviour became a much more regular occurrence once a very high response power source became available, but the control of the current surge became much more easy, resulting in a much more consistent weld bead shape. Using this equipment brought the control of weld penetration to +/- 0.3mm.

Work then diverged to cover other welding processes, materials and joint profiles other than simple butt welds. Lap joints in aluminium, welded by M.I.G. (G.M.A.W.) was also investigated. This joint format being selected because it required only a marginally different probe placement than the butt welds. Using joints of this format required a weld seam following strategy to undertake this task with only one viable signal path. There were no differences in the overall technique when other metals or processes were involved which demonstrates that this control process exploits basic and fundamental materials behaviour. If a weld pool exists, then this control logic will be available because ultrasonic shear waves are ideally reflected by the liquid/solid interface. Weld pools were created by T.I.G. (G.T.A.W.) welding and the growth of these pools monitored ultrasonically, once more showed that all the ultrasonic responses were from the weld pool and not from any other arc/work-piece interactions.

Fillet welds, as a type of joint, are probably the most common form of joints, and once the fundamentals of the process were understood then joints of this format were investigated. Beam paths available for control and monitoring of these joints is illustrated in figure 4. This shows that the joint following is really only on the vertical member (in this figure), the continuous member not being available, having no reflection surfaces on the leading edge signal. A second order approximation was possible based on the position of the weld pool, but this pre-supposed that the weld pool would be regularly positioned relative to the joint. Despite this, seam following ability to +/-0.3mm was shown to be regularly available. A small, crawler robot was designed, accommodated and demonstrated to follow the joints in an internal box section, (as typified in lower hull section designs). This robot sought the joint, back-tracked to an end point (i.e. where the fillet joint ended) and
would have commenced welding. (Work ceased before welding was attempted due to financial constraints, however it was believed that the weld control and accuracies (pool size, penetration) would have matched that already determined.) After some difficulties in finding a strategy for this robot to negotiate tight corners, it was shown that this robot could carry over 100 kg and yet still follow the seam to accuracies of +/- 0.3 mm.

Ultrasonic control of welding was attempted on thinner materials (i.e. < 10 mm thickness) with considerable success. Materials as thin as 0.25 mm, were welded, using plate surface waves instead of shear waves. Both fillet and butt welds were investigated, as was seam following. Penetration could be controlled to 0.05% of plate thickness, whilst seam following was still +/- 0.3 mm (20).

To offer completely automatic welding, two further aspects were deemed necessary, these were i) defect detection in real time and ii) incorporation of an expert system for total system control. Defect detection (in real time) is possible and at the current time being investigated. Defects such as cracks and lack of fusion can be readily monitored and identified at fusion welding speeds, with porosity of < 1.0 mm in diameter being readily identified with cracks, lack of fusion and other planar defects of about 0.3 mm also determined (21). The establishment of an expert system for control welding by ultrasonic means was initiated at the same time as seam following was investigated (22). This expert system was initially one which compared the achieved weld pool shape and position with a desired (pre-programmed) sizes and locations. Simple logics were programmed into the control computer memory and operated as a series of "pull down" charts with very simple decision points. Some success was achieved, certainly on a demonstration basis. Currently work is continuing to develop further this system to control laser welding in the ship-building industry (BRITE/EURAM project BE4331).

This European project ultimately seeks to control the process by neural networks, there is however, one very fundamental philosophical point which must be answered. This question is "once defects are located and identified what controls are available? How does the system react?" Once the defect(s) are determined and sized the expert system will decide if these defects are acceptable to the (desired) standards, if they are acceptable, welding continues, but if these defects are unacceptable, what does the system do? Does it stop the process, does it mark a defective area, does it sound (operate) alarms? This problem, not a technological/scientific difficulty, is the current block on progress.

CONCLUSIONS.

In-process welding has been described and satisfactorily used in a variety of welding processes, utilizing ultrasonic sensing techniques. Accuracies to +/- 0.3 mm have been achieved for lack of penetration as well as real time defect assessment.

Future developments of the system will need to include evaluation
of defects sizes via the method described to accept/reject welds based upon a pre-defined in-service requirement. Once this stage has been achieved then the burden of post-weld inspection and assessment will be an extinct skill and best estimates suggest fabrication cost savings approaching 30% may be achieved. Increased security should also result from much enhanced control of the welding process and decreased chances of undetected defects existing in crucial situations.

REFERENCES.

21) Lu Y and Fenn R: 'Real time defect detection in fusion welding', To be published.
Figure 1: Schematic Diagram of U.S. Beam Spread and three sensing signals

U.S. Transducer

Penetration Sensing signal

Arc

Seam

Trailing edge signal

Leading edge signal

Figure 2: Schematic diagram of relative position of electrode and point of maximum penetration

Point of maximum penetration

% of electrode

Delay about 0.5 secs

Figure 3: Signals associated with under/over penetration

Incomplete Penetration U.S. Recorder Over Penetration

T = Transmission

R = Received signal

D = Desired path

Figure 4: Beam paths in fillet welds
Vehicle Repair and Maintenance Information System
B. Pieters
INTRODUCTION

The Vehicle Repair and Maintenance Information System (VERAMIS) was developed by Intergraph for KLM (Royal Dutch Airlines). This article gives an overview of the KLM "VERAMIS" aircraft repair management system, now implemented and in-service, but the method and individual components can be applied as a generic system to similar requirements in aircraft repair management or other large equipment management.

The purpose of the KLM system is to provide an aid for the detailed management of repairs and inspections needed to maintain aircraft in an airworthy condition. This includes viewing records of previous repairs, completing designs for new work, recalling existing drawings or CAD files, and providing details of inspection requirements. The use of computer graphics to provide rapid access to all relevant information in 2D or 3D form improves efficiency and air safety.

GENERAL CONCEPT AND APPLICATIONS

Many commercial aircraft are being operated over increasingly long periods which may exceed their originally planned economic life. Regular and efficient maintenance is therefore extremely important, as is the need to check for undue stress of corrosion in the airframe. Formal actions taken to deal with this situation include the "Airworthiness Directive Note", a regulatory instruction specifying the information that aircraft maintenance companies must hold and make available for official purposes.

In practice, maintenance engineers need to perform repairs and checks as efficiently as possible, ensuring maximum attention to safety at all stages. A system to record all previously executed repairs, to provide detailed drawings used in design or repair design, and to give instructions that accord with mandatory regulations with a list of the steps to be taken, is a necessary aid for maintenance engineers. The aim of VERAMIS is to provide a system which is fast, multi-use and guarantees integrity in this task.

In designing a generic system and customising it to meet KLM requirements, Intergraph provides the following structure and applications on standard commercial workstations, networked to allow all seats to have access to all data and provide rapid response:

- Interactive, integrated system for accessing, drawing and recalling plans and technical documents relating to aircraft construction.
- 3D visualisation to identify and display perspective views of aircraft parts within the overall structure. The perspective to be variable in view point, cone of view and "zoom" range.
- Registration for repairs, to include authority, date and task completed. This to be linked to the visualisation capability.
- Incorporation of, and conformance to, industry standards and legislation requirements. The VERAMIS system complies with the Airworthiness Directive Note regulations.
- Networked workstations to allow all seats access to all data and sub-systems; this to include file-sharing.
- Multi-user accessories e.g. printers.
- Extendable storage capacity for database.
- Links to existing databases where applicable and the use of industry standards.
- Off-line data links to outside manufacturers.
- A reporting system.

The 3D Aircraft is partitioned for fast access

SOFTWARE PRODUCT CAPABILITIES

The system is an integrated product using the following standard Intergraph software packages:

I/EMS Intergraph/Engineering Modelling System. A general purpose 3-D design and drafting system that enables the user to quickly and efficiently create models and drawings using a simple, easy to use menu system. Based on Non-Uniform Rational B-Splines (NURBS) and a double precision floating point database, I/EMS support a full complement of wire-frame, surface and solid geometric elements. In VERAMIS, this software is used to create the 3-D aircraft reference models.
I/DESIGN general purpose raster data editor that is fully compatible with I/EMS databases. I/EMS surfaces and solid objects, wireframe geometry placement and manipulations are displayed using this software. I/DESIGN serves the needs of scanned drawing maintenance as well as offering a full colour paint package, and can be used to merge scanned manufacturer drawings with specific repair instructions.

RIS Relational Interface System is a standard component of the Intergraph system used to access any of the standard database systems Intergraph offers, such as Informix, Ingres and Oracle. This product makes the corporate database(s) available throughout the network whether centralised or distributed.

DB/ACCESS Database Access is a "forms driven" product running on RIS to provide easy user access to databases. It consists of a menu interface to retrieve, add, modify or delete data from the database as well as a forms driven report writer. This software is the primary user interface eg menus and reports.

I/SCAN Intergraph/Scanning software provides the interface to any of the scanning devices Intergraph offers. Functionality for thresholding, image enhancement and continuous tone scanning is provided.

DATABASE

The system established by KLM uses a central Relational Database to store information for inspection visits and repairs, and includes the (graphic) position of individual components in relation to the aircraft "model". The user can choose to work with either an aircraft model (by specifying a specific aircraft, or by selecting an aircraft configuration eg 747-200-PAX) or a line replaceable unit. In both cases, the system will present a simplified 3-D model to the user, which is generated using I/EMS. The models are used in a read only mode and by applying the capabilities of the system the user can "navigate" through the model until the area of interest is found. It is also possible for a user to choose to work only on, say, section 41 top half and the system will then change the view of the model to reflect this selection. Sometimes a different approach may be necessary and the user can ask the system to retrieve previously stored repairs from the database using a forms driven selection mechanism. Once the filter is set, VERA-MIS requests the information from the database and shows the result in the appropriate 3-D model using repair markers. A marker is simply the repair number with a left arrow indicator which points to the exact location of the repair. Repair markers will show up with different colours depending on the type of repair eg red for major repairs and yellow for corrosion repairs. After the repair markers are placed on the screen, the user can retrieve more information on selected repairs by pointing with the mouse cursor. The results can include alphanumeric information, as well as the related repair drawings.

REPAIR REGISTRATION

When an aircraft is inspected an entry will be made in the database. Typical data to be added will be the inspection type, flying
hours completed and the number of landings made etc. All details of any inspections or repairs made are then attached to this record, including related records such as inspection forms, repair manual instructions and drawings. Any repairs are then marked in their physical locations (in the 3-D model) with a link (repair marker) to all corresponding alphanumeric data. In the KLM system, a repair is always related to a page from the Structural Inspection Manual.

With VERAMIS, different colours indicate different types of repairs.

For some repairs a 2D graphic instruction (ie a drawing with text) is needed to guide the maintenance engineer. This is termed a repair drawing and may need to be approved by the manufacturer. In VERAMIS, the engineer has the option of copying an existing drawing or using drawings previously scanned into digitised form by the manufacturer. Using IDESIGN software the engineer can then design and draw electronically the necessary repair instructions and repair drawings, using the existing drawing as a guide if necessary. VERAMIS software will create and update border information and store or retrieve drawings and scanned images, making them available to all authorised users on the network. Paper copies can be produced using standard Intergraph plotting software. All repair reports and repair drawings are automatically related to an inspection visit. There is no limit to the number of drawings, inspection forms etc that may be recorded against one repair.

Example of a repair drawing related to a repair number

SOLUTION SUMMARY

- Visualisation system. An ability to select one aircraft or a group of aircraft and present 3D schematic perspective drawings of chosen part or parts. Selection to be via a variety of queries. The point of view to be selective and variable by the operator.
- Repair registration. Recall of repair related, alpha-numeric data by indicating the selected part in the visualisation system. Data updating to occur interactively remotely or automatically. Groups of repairs to be accommodated via one query.
- Drawing system. An ability to populate a digital database from graphical and digital data. Acceptance of drawings from outside as well as inside
the system, and capabilities to identify red-line, modify, re-draw and re-publish documents up to A0 size.

- Rapid response. A system suitable for shop-floor maintenance activities as well as management information, i.e. better than 5 sec for drawing recall; better than 5 minutes for A0 print-out.

- Cost effective. For VERAMIS an essential achievement was to produce gains in efficiency and quality.
Abstract

This presentation is all about enterprise wide information consistency and cutting out non value adding processes. It is not about CAD, CAM, MRP, DTP or whatever other acronyms we have.

It assumes enterprises have tools in place for all the above but have severe problems to integrate the information resulting from working with these tools and relate it to the product manufactured in a consistent way.

PPDM can help you to cut out a massive amount of non value adding work and deliver end-to-end configuration management and traceability from design to production and even through the total maintenance cycle for all used documents, tools, materials, etc.
As a starting point, we assume a manufacturing company is well equipped and organised within its individual departments. Most of the interactions between departments are based on paper documents and internal mail.

In many cases, sales, purchasing and material management departments use a common MRP system which provides a certain degree of information integration. In addition design and engineering have their own systems which work well within their own environment but, at the most, can export bills of materials to the MRP system and CAM files to PLC's (with very limited version control and with no relationship at all with the production schedule).

While this description is very much simplified, it is clear that no manufacturing company can deliver end-to-end consistent records on the products they build. For most products in the market you can say: "YOU CAN SEE THAT IT WORKS BUT YOU CAN'T PROVE IT". This is not good enough to meet the new safety and quality regulations of the 90's.
While God created mankind in six days, it takes several decades to build a large company with all the necessary personnel and systems. Technology however also evolves, causing a multiplicity of organisational methods, media and routes...

For the sake of this presentation, every information carrier is called a DOCUMENT.
The consequence of this multiplicity is that massive non value adding effort is spent in document handling throughout a company, all of which is within the mainstream of the company's processes adding up lead times and risks of information inconsistency.

RESULTS

- VERY LONG LEAD TIMES
- HIGH MANPOWER REQUIREMENTS
- EXCESSIVE MATERIAL IN STOCK AND IN PROCESS
- HIGH PERCENTAGE OF SCRAP AND REWORK
- LOW QUALITY
The solution we propose is called PPDM, Product and Process Document Management. It was built by Boeing Computer Services as an electronic document management solution in the late 1980's.

While Boeing had a large IBM and DEC installed base, they decided that PPDM, being an on-line document management application, could only run on a Fault Tolerant on-line Transaction Processing (OLTP) environment. Tandem, as a recognised leader in Fault Tolerant OLTP, was chosen as the platform of choice.
PPDM should be viewed as an umbrella over all existing document handling applications. It allows for a single, consistent view over all documents related to products, processes and resources of a company.

PPDM does not replace existing applications, in fact, PPDM does not contain any functionality in the area of CAD, CAM, Word-processing etc. It contains and maintains only meta-data, information about users and their capabilities, computer and network configurations and its capabilities, applications and their interfaces, and organisational procedures (work flow templates) describing how users handle corporate data. At execution time, PPDM keeps track of versions and relationships of new documents and logs how work flows are executed providing full traceability and configuration management.

Tandem's superior connectivity within existing computer installations, make PPDM applicable in any situation without adding equipment on the end-user's desk. In fact it can even minimise the number of workstations needed on the end-user's desk by doing session management allowing windows into all the different applications needed by the end-user.
## PPDM SOLUTION

**MAJOR FUNCTIONS AND BENEFITS**

- **ALL DEPARTMENTS WORK WITH IDENTICAL DOCUMENTS**
  - FEWER ERRORS, LESS WORK
- **INSTALLED PPS, WORKSTATIONS, DTP SYSTEMS, PLOTTERS, SCANNERS CAN BE CONNECTED TO PPDM**
  - CORRECT HIGH-GRADE INFORMATION AVAILABLE WITHOUT DELAY
- **INFORMATION FROM CAD, PPS, PRODUCTION PLANNING AND NC PROGRAMMING SYSTEMS CAN BE PUT TO GREATER USE**
  - HIGHER PRODUCT QUALITY
  - SHORTER PROCESSING TIMES
- **NO TIME-CONSUMING SEARCHING FOR OLD DRAWINGS, WORK PLANS, ETC.**
  - LESS DUPLICATION OF WORK
  - LOWER STOCK LEVELS

## PPDM SOLUTION

**WHAT DOES IT CUT OUT?**

- MONITORING OF MODIFICATION PROCESS
- WORKING WITH OBSOLETE DOCUMENTS
- ERROR SEARCHING
- MANUAL DISTRIBUTION
- SEARCH WORK
- DOCUMENT TRANSPORT TIMES
- REPORTS, DOCUMENTS WITH DIFFERENT VIEWS, LOGIC
- MANUAL CONTROL OF USAGE AUTHORIZATIONS
- MANUAL ARCHIVING
PPDM SOLUTION

<table>
<thead>
<tr>
<th>MAIN BENEFITS</th>
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<tbody>
<tr>
<td>SHORTENS PRODUCT-DEVELOPMENT AND ORDER LEAD TIMES (FROM DESIGN TO PRODUCTION)</td>
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<tr>
<td>IMPROVES DOCUMENT AND INFORMATION QUALITY</td>
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<tr>
<td>INTEGRATES DATA VARYING FORMAT FROM DIFFERENT SOURCES (DESIGN, OPERATIONS, SCHEDULING, PRODUCTION)</td>
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<td>SIMPLIFIES ACCESS TO INFORMATION, ALSO OVER LONG DISTANCES</td>
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<tr>
<td>MONITORS AND DOCUMENTS CORRECT IMPLEMENTATION OF ALL UPDATING AND RELEASE PROCESSES</td>
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<tr>
<td>REDUCES PAPERWORK</td>
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<tr>
<td>AVOIDS SCRAP AND COSTLY REWORK CAUSED BY WRONG INFORMATION</td>
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<tr>
<td>INCREASES SECURITY AGAINST UNAUTHORIZED ACCESS TO IMPORTANT DATA</td>
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PPDM is no magic. It can't turn a bad organisation into a good one. However, it can turn most of the unreliable and time consuming non value adding document handling work into fast, reliable, well managed and logged automated processes.
The efficiency gain of PPDM is in the middle of the company's mainstream. It reduces the overhead allowing lead times to consist of almost only value adding productive work time. In addition to the extreme short ROI time, PPDM dramatically reduces the "time to market" making your company much more competitive.
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