DESIGN INNOVATION IN SHIPPING

Prof. Dr. Ir. N. Wijnolst

the only constant is change

DESIGN INNOVATION IN SHIPPING

The only constant is change

Prof. dr ir N. Wijnolst

DELFT MARINE TECHNOLOGY SERIES

1. ANALYSIS OF THE CONTAINERSHIP CHARTER MARKET 1983-1992
2. INNOVATION IN FOREST PRODUCTS SHIPPING
3. INNOVATION IN SHORTSEA SHIPPING: SELF-LOADING AND UNLOADING UNITLOAD SHIPSYSTEMS
4. NEDERLANDSE MARITIEME SEKTOR: ECONOMISCHE STRUCTUUR EN BETEKENIS
5. INNOVATION IN CHEMICALS SHIPPING: PORT AND SLOPS MANAGE-MENT
6. MULTIMODAL SHORTSEA TRANSPORT: COASTAL SUPERHIGHWAY
7. DE TOEKOMST VAN DE NEDERLANDSE ZEEVAARTSECTOR: ECONOMISCHE IMPACT STUDIE (EIS) EN BELEIDSANALYSE
8. INNOVATIE IN DE CONTAINERBINNENVAART: GEAUTOMATISEERD OVERSLAGSYSTEEM
9. ANALYSIS OF THE PANAMAX BULK CARRIER CHARTER MARKET 1989-1994: IN RELATION TO THE DESIGN CHARACTERISTICS
10. ANALYSIS OF THE COMPETITIVE POSITION OF SHORT SEA SHIPPING: DEVELOPMENT OF POLICY MEASURES
11. DESIGN INNOVATION IN SHIPPING

DESIGN INNOVATION IN SHIPPING

Prof. dr ir N. Wijnolst

with assistance from ir F.A.J. Waals

DELFT UNIVERSITY PRESS
1995

Published and distributed by:

Delft University Press
Stevinweg 1
2628 CN Delft
The Netherlands

Tel: +31-15-783254
Fax: +31-15-781661

CIP-DATA KONINKLIJKE BIBLIOTHEEK, THE HAGUE

N. Wijnolst

Design Innovation in Shipping/ Wijnolst, N.
Delft: Delft University Press. - Ill. - Lit.
ISBN 90-407-1143-7
NUGI 834
Keywords: Innovation, shipping, design

This book is dedicated to my father, Daan Wijnolst, who worked with the Port Authority of Rotterdam and who taught me in my early years "design by drawing".

Table of Contents

INTRODUCTION

The focus

The title of this book is *"Design Innovation in Shipping"*, which deserves an explanation. I shall start with the word ***Design***. The Delft University of Technology is the oldest and largest engineering school in The Netherlands, with approximately 14,000 students. Engineers are taught the basics of design in all the domains of engineering, which are organised in thirteen faculties. At the Faculty of Mechanical Engineering and Marine Technology the students learn the skills of designing, and the science of ship design and of other maritime structures (offshore).
The design of ships, or 'naval architecture', is part of the oldest curriculum at the University. Since its inception in 1842, naval architecture was one of the five subjects taught at the young engineering school. It may seem strange that a landlocked city like Delft should develop a main course in ship design at that time. However, Delft had a port, although at a short distance, connected by a river to the city of Rotterdam, called Delfshaven. In this port, a shipyard built the ships for the famous Dutch East Indies Company, of which the city of Delft was one of the six constituent partners since its founding on March 20, 1602. Besides, it was there that the Pilgrims commenced their journey to North America in 1620. This explains the roots of the Faculty and the long tradition in shipping and ship design.

Since May 1, 1988 I am a halftime professor at the Faculty, were I teach three subjects: shipping and running of ships, design innovation in shipping, and maritime business studies.
During the seven years that have passed since, I have been in the fortunate position to work with many graduate students on thesis projects that were all focused on the three forementioned themes. In the beginning, my approach of design was intuitively directed towards the triggers from the market that led to innovation in ship design. On the basis of the experience from teaching innovation in design, supervising innovation thesis projects and doing consultancy work in the maritime industry, I came to the insight that the current design methods do not adequately equip the students with tools to systematically approach market-driven design innovation in shipping. Over the years, I have been able to incorporate new concepts, borrowed from other sectors, in the design process. This led to a new paradigm for design innovation in shipping, which is described in this book.

Innovation is the second word in the title. What is innovation and why bother to incorporate this notion explicitly in the design process? The designers use already use their creativity in the different stages of the design process, so how can this be improved? The sceptics have reality on their side. The history and present of shipping is well documented with an unprecedented number of basic innovations and improvement innovations. Some of the major innovations in shipping came even from individuals outside the maritime sector, such as the container.

The rationale for a design cycle that includes explicitly *innovation* is based on the ever growing competitive environment in which shipowners and shipyards try to survive. Creating a sustainable competitive advantage is the only protection for owners and yards to stay ahead of the game. Innovation is a 'must' if the company wishes to maintain a competitive edge. This is not only for companies. At the national level, innovation is the only lasting source of creating wealth, as M. Porter has well documented. The Netherlands is a small country with a still growing population; however, the numbers of hours worked by its population stagnates since 1960(!), and remains almost constant over the last 35 years: 8 billion hours per year. Over the same period, the workforce has doubled (**Figure 1**). The Dutch economic policy has thus been to redistribute work and income, and not aimed at creating wealth. Some observers call this policy 'redistribution of poverty'.

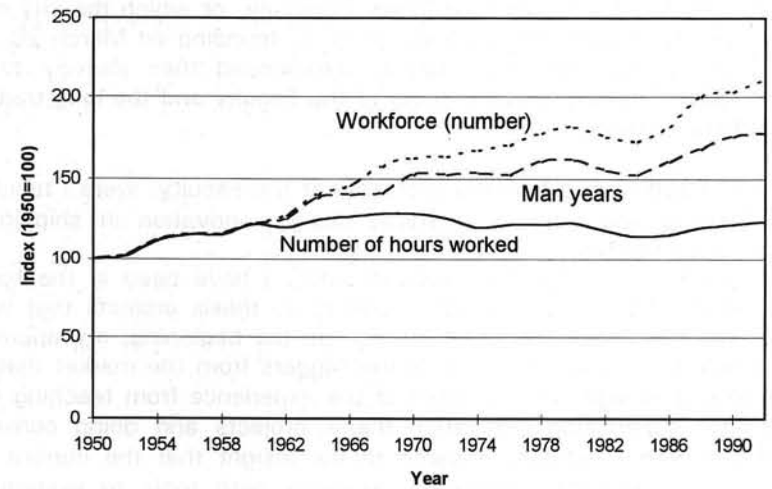


Figure 1: Workforce vs. hours worked

According to drs. J.C. Blankert, the Dutch entrepreneurs have to continually: renew products, processes and services, control and reduce costs, improve the quality of products and services. This requires a continous search for technological deveopments or innovations, which has to take place ever faster. A condition for keeping up with this international trend, is to invest heavily in research and development. However, the Dutch economy is lagging seriously behind other developed nations in this respect. Mr. Blankert quotes the following figures to illustrate the relative decline in Dutch R&D spending. "*The governmental budget for R&D has declined since 1987 from 1.13% to 0.82% of the GNP, a drop of 27%! At the same time, the equivalent budgets in OECD-countries increased with 5 to 13%.*"

A recent report by two Dutch ministries, Economic Affairs and Education, rephrases the decline as follows: "*If The Netherlands were to achieve the average level of R&D investment as the 25 richest OECD-countries, than it should invest per annum an additional NLG 2.5 billion. At the same time, the number of companies doing R&D work has declined sharply from 1988-1992: from 6000 to 4300.*" The ministries comment further that "*The company R&D goes abroad, while the research institutes are not able to attract enough foreign R&D work.*"
This underlines the absolute need to focus the engineering student's education on the R&D work which is closely related to innovation.

The last word in the title is ***Shipping***. Why not use the word *shipbuilding*, which should be more appropriate at an engineering school. The difference is important and can be traced back to the history of basic innovations in ship types. These were hardly ever triggered by naval architects working for shipyards, but mostly by shipowners. These owners know the logistical costs of the current transport chains and are continuously looking for ways and means to reduce these costs. This provides them with the triggers to innovate. As there are almost as many logistical chains as their owners, there is a constant influx of new ideas and concepts. In some instances the demand side for shipping is not the driving force behind change; it can also be driven by technological innovation, such as propulsion systems or fast ships. Whether innovation is created by market-pull or technology-push is not so relevant for the design process. The owner will benchmark his performance continuously in comparison with the competition. The systematic benchmarking of the critical success factors is a major source for triggers of innovation. The central theme of the book and its extension of the design methodology is based on the preliminary, conceptual design phase, in which triggers for innovation are systematically identified and translated in to new concepts.

The book provides the reader with a very wide conceptual framework of design, innovation and shipping. It is meant in first instance as course material for my lectures in this domain. The theory in the book is as much as possible illustrated with real world examples. A number of case-studies of innovation studies, which are based on thesis projects or my own research, document the design methodologies. Wasn't it Newton who played down his own contribution to science, when he said that it was only made possible because he had stood on the shoulders of giants (his predecessors)? Although I do not want to pretend to place myself in the same bracket as Newton, I feel that I too am indebted to many authors, colleagues and students, who helped me to develop my conceptual framework and add some new ideas. I have freely quoted many authors, the Chapter Notes contain a large reference list in which all the authors of books, reports and studies that I have used, are mentioned and acknowledged. If I have omitted anyone, please accept my apologies.

The Chair

I am grateful to my current students and the ones that have graduated since the creation of the chair in the academic year 1973/74 by Prof.ir N. Dijkshoorn. I took over after his retirement in 1988. Some 86 engineers have graduated with the chair, which are equally divided between us.
The chair was founded on the basis of a government initiative at the end of the 1960s during which period the Dutch maritime sector went through a severe stage of transition and restructuring. Major changes in world shipping, like the introduction of the container and the rapid expansion of dry bulk and tanker shipping, led to the insight among policy makers, the business community and the university, that the curriculum of the naval architect was too much focused on technology alone. The engineering education should provide the student with a wider perception of shipping, naval architecture and shipbuilding.
The chair has achieved these objectives over the more than two decades of its existence. The results are appreciated by the maritime sector, which is not only demonstrated by the hiring of the graduates, but also by the financial support they offer to the chair.

Acknowledgements

The ongoing financial deficits of the Dutch government budgets have created a pressure on the universities to reduce costs dramatically. Since my appointment at the Chair, the number of professors (full and part-time) at the Faculty of Mechanical Engineering and Marine Technology whom are paid directly by the government has been reduced from by two-thirds, and the downward trend still continues. As the industry wished to maintain a number of part-time chairs, outside financing and sponsoring of academic chairs has become a common phenomenon.
My chair has been financed since May 1, 1992 by some thirty companies and institutions from the Dutch maritime sector. The sponsors are united trough the *Stichting Leerstoel Rederijkunde*, a foundation, which is governed by a Board[1]. I am very grateful for their support and only because of their collective effort, I

[1]M.J. Muller (chairman), drs W. Cordia, M.J. van Overklift and A.G.C. Kok

am now in the position to write this book and to teach future generations of engineers.

Transforming the raw material for this book into the present format, required a lot of work. Ir F.A.J. Waals provided me with valuable assistance to achieve this. Because of his professional contribution, the manuscript was prepared in a relatively short period. The financial support offered by the Faculty made this possible.

Commentary and suggestions

This book will undoubtedly raise questions, comments and hopefully also suggestions for improvements. These can be directed to:

Faculty of Mechanical Engineering and Marine Technology
Prof. dr ir N. Wijnolst
Mekelweg 2
2628 CD Delft
tel.: +31-15-784682
fax: +31-15-620620

CHAPTER 1: WHO DESIGNS AND INNOVATES SHIPS?

The design and innovation of ships is the work op people, but not necessarily, with an engineering background. These men and women work either individually or in teams. They are employed by shipowners, marine consultants and shipbuilders. The final design is approved and determined by the shipowner, as after all he pays for the ship. The fact that he has this 'power of the purse' may create some conflict with the shipyard, which is logical, as the revenues for the yard are the cost for the owner. This may lead to diverging views on ship design, as the owner wishes to maximise the revenues of the ship during its commercial life, while the yard has a short term goal, making money on the construction. These diverging objectives are nicely symbolised in **Figure 1**, from the design brochure of the former Wärtsilä-yard. The shipyard views the ship as collection of technical systems, while the shipowner only sees freight revenue, its earnings potential. It will be evident that it is therefore important to define the position of the ship designer.

Other parties than the shipowner and shipyard can be involved in the design process as well, for example independent naval architects or shipbrokers. The latter category is very close to the market, the place where demand and supply of ships meet. Therefore, the shipbroker is often in a position to see opportunities for new ship concepts, or improvement innovations.
A good example is the Superflex product tanker design from the Norwegian shipbroker Libaek. **Figure 2** shows the classic single hull design, and **Figure 3** the superflex design. The advantages - quick tank cleaning and the possibility of eliminating ballast voyages through triangular trading - of this design were such that some 140 ships have been built worldwide based on this concept.

In some instances, for example gas tankers, there is another important player involved in the design of the ship: the tank designer and manufacturer. The tanks constitute such an important part of the total investment in the ship and require such a specialised knowledge, that design is the result of the triangular discussion between owner, tank designer and yard (**Figure 4**).

This complicates the design process since it adds yet another objective, that of the tank designer. He likes to make nice, bi-lobe tanks that fit snugly into the hull; the smallest hull, as the yard wants to minimise the light ship weight. These complicated tanks are relatively expensive, in comparison to simple cylindrical tanks. Simpler tanks are against the objective of the tank designer, and require more space in the ship's hull, which is against the objective of the yard.

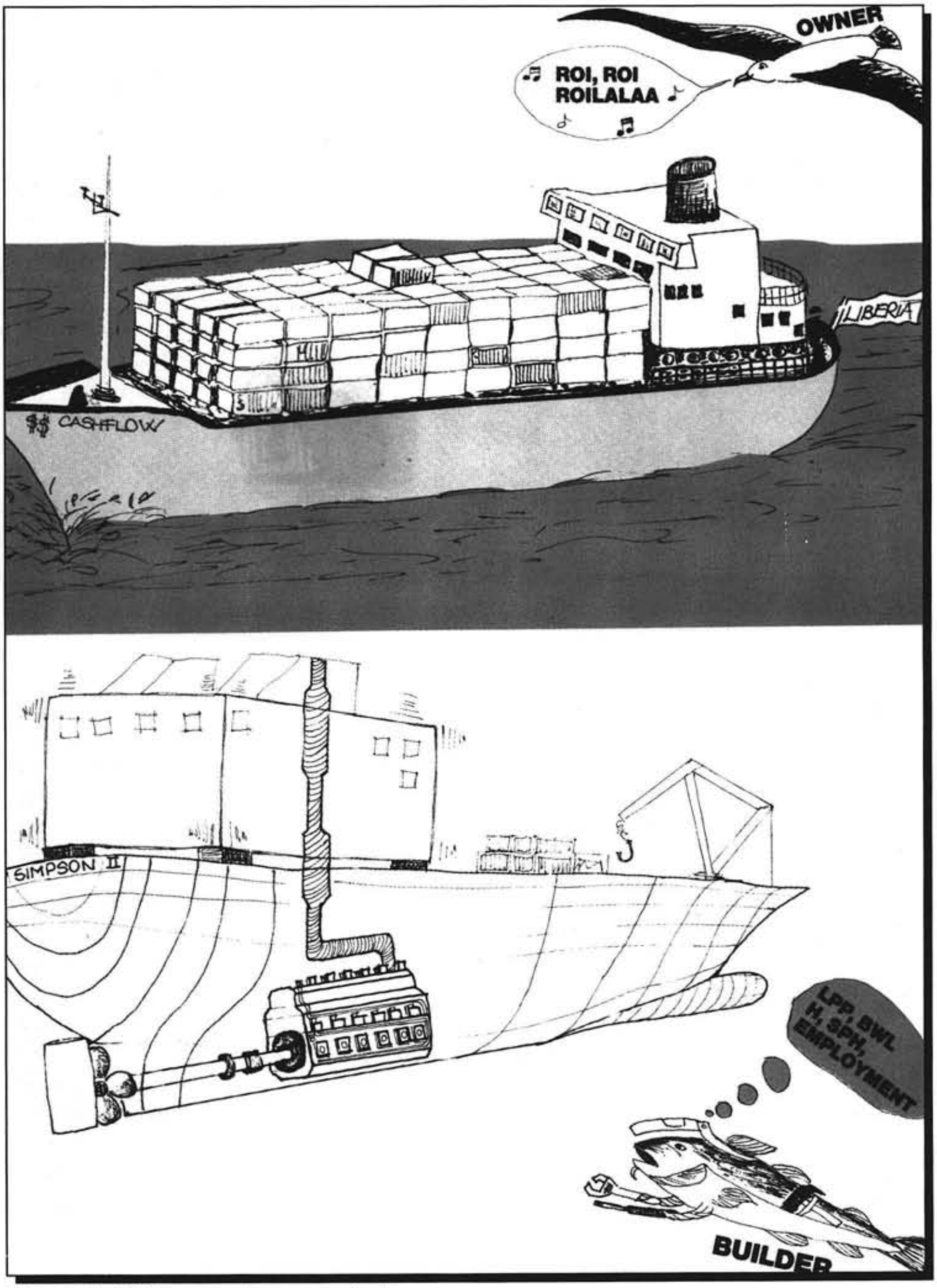


Figure 1: Different views on design

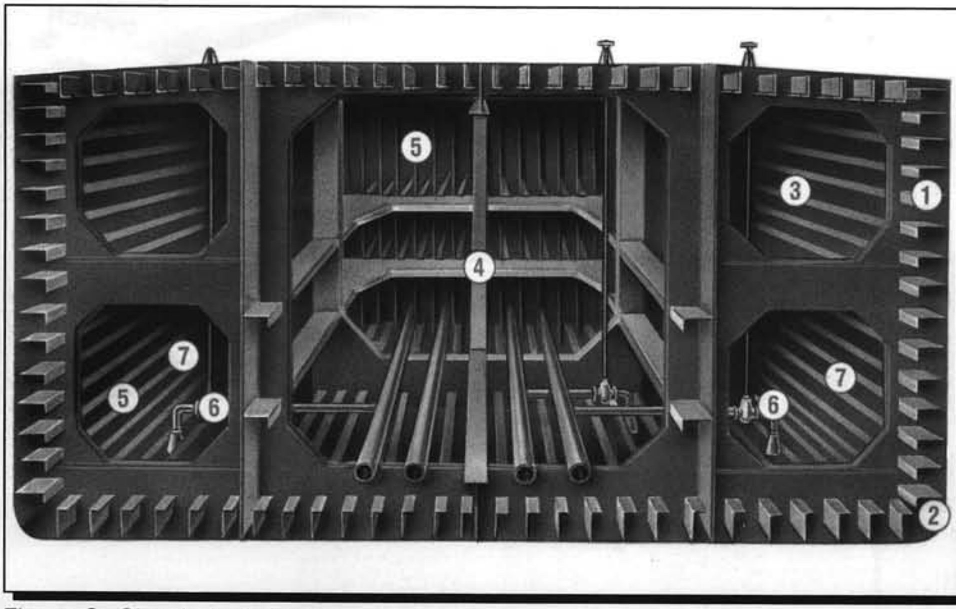


Figure 2: Classic hull design

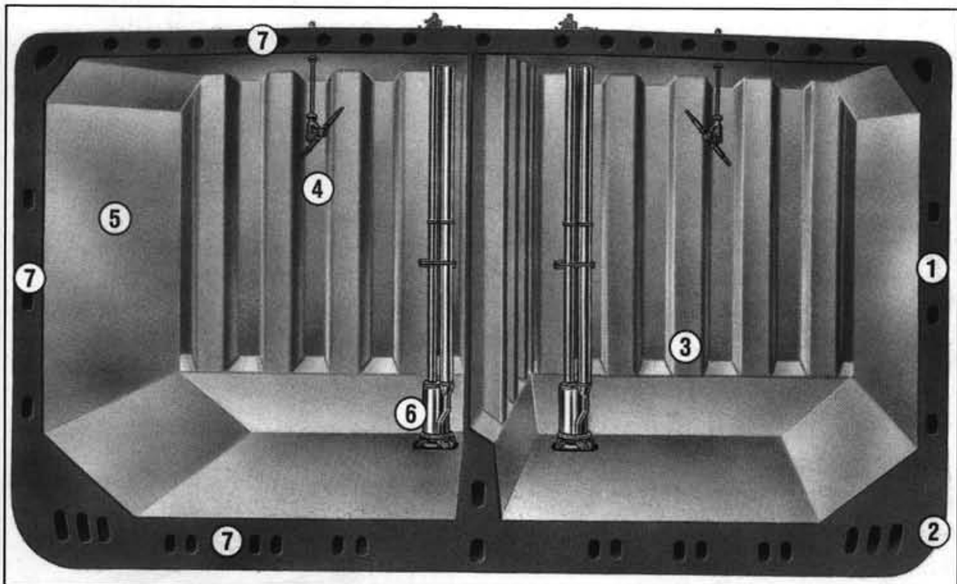


Figure 3: The superflex design

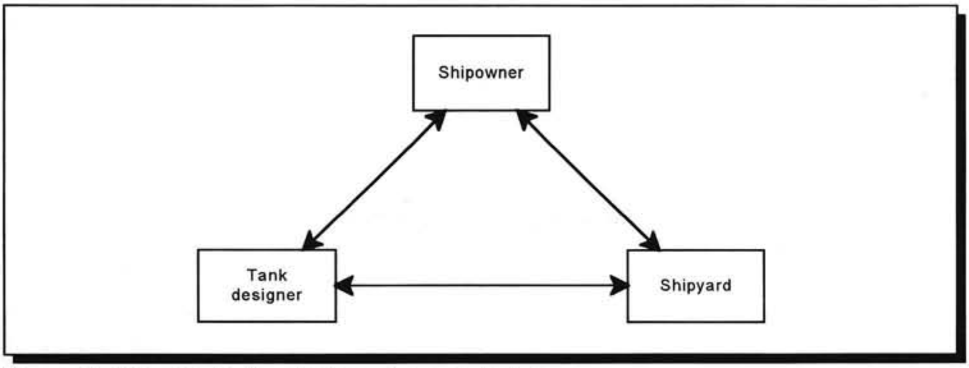


Figure 4: Players in the design of a gas tanker

However, it might very well be possible that the shipowner is better off with this combination. The case-study in this book on gas tankers (**Chapter 15**), illustrates this thesis with an example from the real world; significant savings can be achieved by using the combination of simple tanks and a slightly larger hull.

There are two other parties associated with ship design: classification societies and the International Maritime Organisation (IMO). The classification societies develop the design rules for all sorts of ships, which should be met by the shipowner or shipyard. The classification societies have played in the past an important role in the development of scientific methods of ship design and calculation. Also in the present, they are at the forefront of developing new design criteria and design methods, such as the SafeHull system developed by American Bureau of Shipping. However, classification societies do not design ships; they check and approve designs, and they survey the ships during their operational life.
The IMO is yet another body that has developed rules and regulations for the design and operation of ships. These are of a more general nature and may influence the design fundamentally, but are not part of the design itself. A recent example of the way IMO rules influence design are the safety standards for ro-ro vessels. After the disaster of the *Estiona*, the design of the visor-doors at the bow had to be changed. **Figure 5** shows the Kværner design for the new Stena ro-ro, which is to be built in The Netherlands.

The design of ships is often a matter of improving existing ship concepts, rather than the development of completely new designs. A marginal improvement of the design, which is rather a matter of optimisation, can be very well done by the shipyards. A good example is the Panamax bulk carrier segment, where over twenty years of gradual improvement have advanced the concept from a 55,000 dwt. ship to a 75,000 dwt., within the Panama Canal design constraints. The benchmarking case-study on Panamax bulk carriers will illustrate this further.

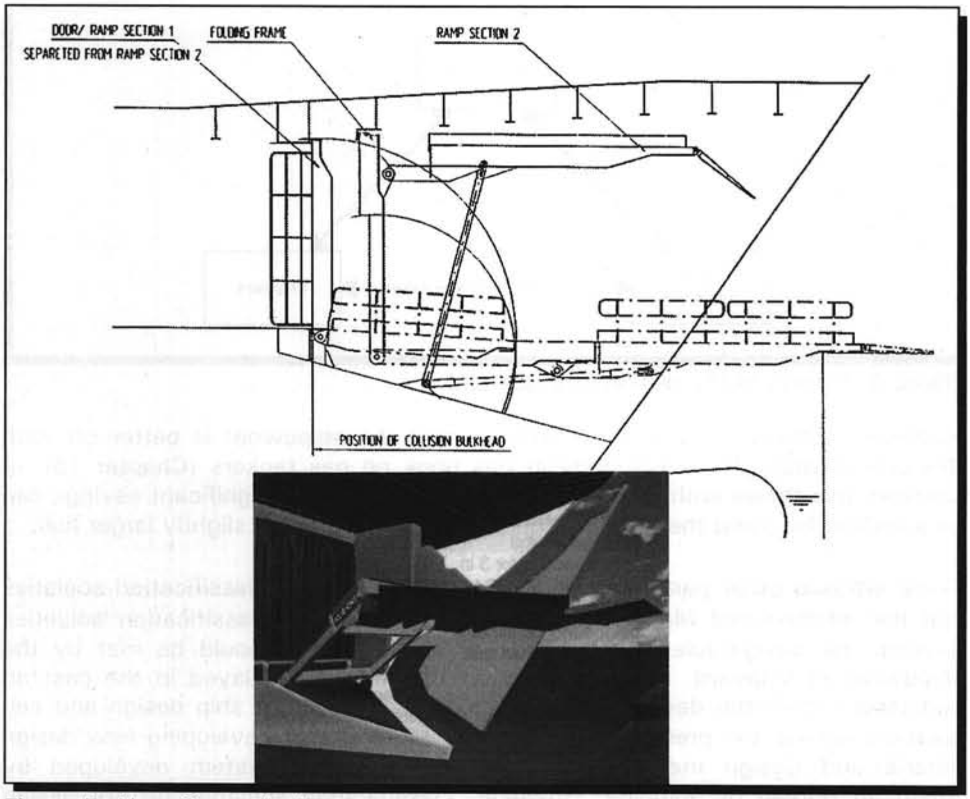


Figure 5: New Stena design

The innovation process will result in a conceptual design, which is followed by a detailed design, which is made into a construction design by the shipyard. Significant innovation takes also place in the construction design through the use of less and more simple components.
Most of the innovative thinking by the shipowner is put into the conceptual design of the ship. That is his domain par excellence. **Figure 6** shows the role and importance of the shipowner and shipyard as a function of the newness (or innovation level) of the design. The less innovative the design, the larger the potential role of the shipyard.

In general, shipyards do not innovate the design concepts of ships, with of course notable exceptions such as the high speed light craft. Many shipowners work in close relationship with yards on new designs, so the picture is not black and white. But the yard's role is often more reactive to the demand of the owner, than proactive, i.e. anticipating and initiating fundamental change.

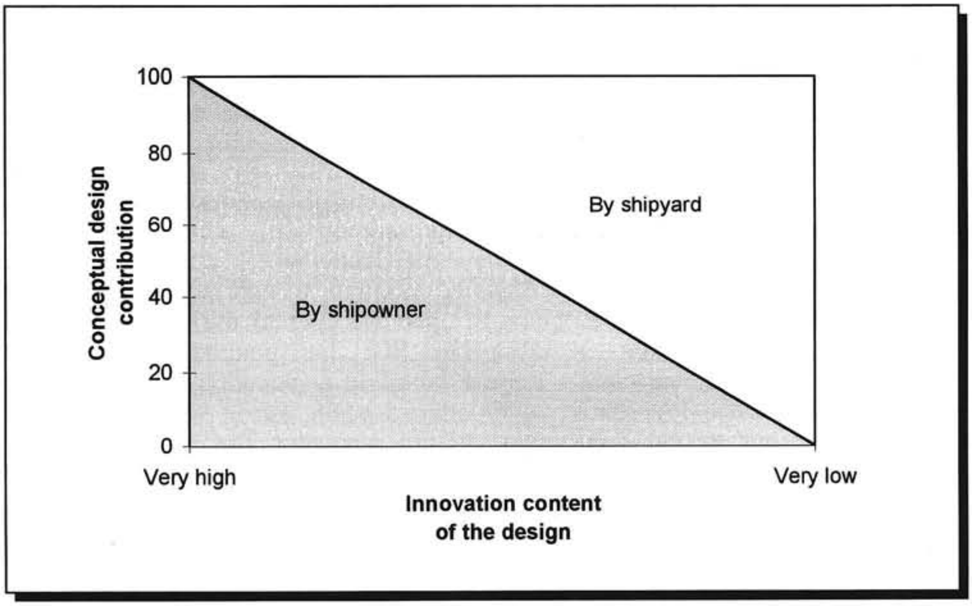


Figure 6: Influence of the shipyard and shipowner on the newness of a design

The reticent attitude of shipowners to be too closely involved with one yard is caused by the desire of the owner to shop around for the best deal. The shipyard is aware of this and does not want to spent a lot of engineering hours on a design that he is not certain to build. So the commitment from the yard towards a new design is often restricted by the cost and uncertain benefits. Sometimes, the yard imposes solutions that are related to production constraints, such as the limited width in the Winschoterdiep, in the northern part of The Netherlands. Most of the yards in that region used to base an *optimal* design (dry cargo, reefer) on the maximum allowable width of 15.85 m.
The advantage of working with a yard in the design process is that it adds manufacturing knowledge in an early stage, which may simplify the structures and/or lower the costs.

A major obstacle for the owner is the reduced capacity to design ships in-house. During the very bad shipping years of the 1980s, most of the shipping companies have eliminated their design staff in an attempt to save costs. The risk is that they shot themselves in the foot, as they are now completely dependent upon outside consultants, who may not be fully aware of the logistical chains in which the ships operate and therefore do not fully understand the triggers for innovation that exist.

In the ideal design environment for achieving innovation and creating a competitive advantage in shipping, the owner has a minimum in-company expertise and analytical skills for the monitoring of markets and operations, as well as liaison with the specialist consultants and builders of ships.

It is up to the shipowner to engineer the business system in such a way that all the expertise required to innovate and design ships is integrated. This demands concurrent engineering, based on a network model, as a lot of the expertise has to come from outside. The organisation of the design process, and the incorporation of innovation, leads to a new design methodology, which is in most of the cases controlled by the decision maker: the shipowner.
This book on *Design Innovation in Shipping* attempts to define such a new approach to design and has the ambition to open the eyes of the engineering students for the whole range of disciplines that are required to become a professional designer. The current narrow focus on engineering *science* instead of engineering *technology* should be broadened again, like it was in the past. Computers do not design ships, they do not represent The Truth, they can merely help the designer with the numerical evaluation. The role of the purely rational design approach should therefore be questioned as it is not the way of the future for engineers who wish to advance technology.

CHAPTER 2: NATURE OF ENGINEERING DESIGN

This book is about Design Innovation in Shipping, which implicitly supposes that it is possible to develop and apply design methodologies and processes that lead to design innovation in the domain of study: shipping. The first question to be answered is whether design can be taught as a rational approach. After all, the development of the methodological aspects of design into a theory, is a relatively recent endeavour. The world apparently could do for centuries without it and progress (read: innovate) nevertheless. Why then the need for more systematic design theories and methodologies to advance innovation in shipping?
That is a difficult question to answer, but for my part, it rests upon three pillars. The first one is educational, the second one ideological or pre-scientific, and the third one is practical.
The *educational* use of design methodologies is that it allows the teacher to demonstrate in a structured way the different phases of the design process in a logical order. The reality of the design process is often much more unstructured and chaotic, but a design methodology may help the student to build his own mental or conceptual model of the process. This is an invisible guideline for his future work, which he can modify and adapt according to his own experiences and needs. The framework function of the design methodology also facilitates the structuring in the curriculum of the Faculty of the different subjects to be taught. It provides the student, teacher and faculty with a collective, unifying vision of the study.

The second pillar is *ideological* in nature. In other words, the teacher, student or practitioner of design methodologies believe that the rational approach to design will lead to a successful result, or at least increases the chances for success. The use of a methodology implies a certain believe in rational design procedures, although within the different steps of the design process, irrational phases - such as idea-generation through creativity - can be used. It is again the engineers paradigm that design can be taught and learned by applying methodologies. There are sceptics who believe that engineering can and should not be reduced to design methodologies. One of these adapts is prof. Ferguson, whose point of view is well documented in *"Engineering and the Mind's Eye"*, which will be discussed in this chapter.

The *practical* reason for the use of design methodologies is that in the real business world shipowners or shipyards cannot afford to wait for the engineer to have explored his 'mind's eye' and come up with innovative solutions. The complexity of the job of ship design requires the involvement of many people, with different knowledge bases, which have to be combined into a holistic approach. Design methodologies are a practical instrument, understood by all

participants, to work together. It is a way to structure the business and organisation of those involved in developing the new, innovative designs. The constant pressure on entrepreneurs in shipping to improve performance, and therefore the necessity to innovate and lower the cost of this process, has lead to an increasing number of design methodologies over the last half century.
In this book a number of the approaches, also others than from shipping, are discussed. They may be a stepping stone for designers to benchmark their own methodologies. The modification of the current design methodology proposed in this book, is an attempt to do this. I believe that all those involved in ship design should once in a while take some time to sit back and think about their own (often implicit) design approach, and see how they can borrow ideas from other sectors. The pace of change is increasing, which leaves less room for failures. The process of design methodologies should therefore itself be a subject of study.

From this short statement you may deduce that I am a strong advocate of teaching and practising rational design methodologies in shipping; not blindly, but with an open mind and making use of the designers mind's eye. That is the challenge for engineers, and the students will hopefully be convinced after reading the remainder of the book.

Origins of the Schools of Engineering

In E.S. Ferguson's *"Engineering and the Mind's Eye"*, the origins of the engineering schools are traced back to the emergence of artillery schools, especially in France at the beginning of the 1700s. At these schools, the cadets were given a grounding in algebra, geometry, trigonometry, and engineering mechanics. The first school for military engineers (as distinguished from artillerists) was established in 1749 in Mézières. This had a crucial influence on the famous Ecole Polytechnique, which was established after the French revolution (1794). That school became the hub from which spokes radiated to 'schools of application', comprising artillery, military and naval engineering, bridges and roads, and mines. The Ecole Polytechnique, a two-year school whose students were chosen by stiff competitive examinations, provided the mathematical core of an engineering education. Its graduates went on to the schools of application to complete their education as specialised engineers. From that time forward, engineering graduates in France enjoyed high political status. The schools they attended became known as 'les grandes écoles'.
Engineering education in the United States followed closely the precedent set in les grandes écoles, particularly in adopting the central core of mathematical studies. The Delft University of Technology was also modelled on the basis of the Ecole Polytechnique and the Grandes Ecoles, and share the same paradigm on engineering education, since its establishment in 1842.

The making of an engineer

Although since the 18th century engineering became a science in its own right, it existed, but was founded on quite a different basis. Ferguson gives an example of the training of men like Filippo Brunelleschi and Leonardi da Vinci (1452-1519) in his book. This included apprenticeships in which they learned how to prepare and use the materials required to make drawings, paint pictures, and produce sculptures in stone and metal. Their knowledge was based on observations of the senses, and they were guided by masters who showed the apprentices what to look for. They were trained as artisans, which today means 'persons skilled in an applied art'.
When, in the fifteenth century, Brunelleschi designed and directed the building of the great dome of the Florence Cathedral, he demonstrated his knowledge of the properties and behaviour of materials, and of the mechanics of an intricate, monumental structure intended to last a long time. It is difficult for a twentieth-century engineer to believe that Brunelleschi could accomplish such an impressive achievement without some help from science. Yet Brunelleschi's knowledge was developed in a world of art, not science.

According to Ferguson, this started to go wrong in 1605 when Francis Bacon developed his programme for a practical new science, based on direct observations of nature, as will be discussed in **Chapter 10**.
From Bacon's time to the present, almost 400 years, promoters of the mathematical sciences have convinced their patrons that science is the way to truth and that it is the chief source of the progressive inventions that have changed the material world. The myth that the knowledge incorporated in any invention must originate in science is now accepted in western culture as an article of faith and the science policies of nations rest on that faith (or paradigm).
Ferguson says that we have become so accustomed to this subordination of technology to science, that it is difficult to realise that the Renaissance engineer, trained as an artist and retaining the artist's use of intuition and non-verbal thought, had significant counterparts in the United States as recently as the nineteenth century. For example, Robert Fulton of steamboat fame and Samuel Morse, inventor of the American telegraph, were both artists before they turned to careers in technology.

Ferguson describes the gradual change from an emphasis on technology and design at the engineering schools in the United States over the last centuries, to a degree that engineering education became engineering *science*. He quotes an MIT report from 1961, in which is stated that young engineers feel at home in solving problems that have numerical answers, the kind of problems used in school for teaching analytical techniques. Also, these young engineers tend to consider problems that do not involve mathematics at least at the level of the calculus as beneath their dignity - something to be turned over to a technician who is without the benefit of a higher education.

The same report made a serious attempt to articulate the nature of design, beginning with the recognition that there is no unique or 'correct' solution to a problem of design. This recognises that design is radically different from the kind of problem used in school in teaching analytical techniques. In order to emphasise the difference, let us look for a moment at the MIT committee's description of the way analytical tools are introduced in engineering schools.
Courses in physics, chemistry, mathematics, and the engineering sciences are all mathematical in form. Students manipulate given data to arrive at numerical answers. In all such courses, questions asked of students are overwhelmingly what will be called single-answer problems. Reasons for the popularity of this type of problem are not hard to find. Single-aswer problems provide an essentially objective standard against which the performance of the student can be measured. The student can be taught a series of logical steps to arrive at the answer. The teacher can measure his own effectiveness by noting the percentage of his students who arrive at the right answer when tested. Because of the existence of an objective standard, people inexperienced in engineering, graduate students for example, can be, and often are, entrusted with teaching.
The educational problems posed by these ubiquitous single-answer problems - providing not an objective but an arbitrary standard - are several. There is no need to deal with incomplete or contradictory data; any ambiguity merely represents a mistake in stating the problem. One does not need engineering judgement to solve such problems. "*Skepticism and the questioning attitude are not encouraged in this situation*" said the report. "*Neither the data, the applicability of the method, nor the result are open to question*".

Turning to a description of the design process, the committee averred that design "*is done essentially in the mind*", that drawings are pictorial extensions of the mind (an external and reliable memory), and that "*it is not to be expected that all students are equally endowed with the ability to think pictorially any more than to think mathematically. Somehow educators tend to look upon mathematical ability as a more desirable quality than the ability to think in terms of spatial relations.*"
Because design is a conceptual process, one in which at least a fragment of a mental plan is necessary before the process can proceed, synthesis must come first. Because the object being designed is almost always far too complex to permit analysis directly, a simplified model must be devised to permit calculation. And although the use of automatic computation makes it possible to use more complicated models, it should not be assumed without proof that a more complicated model represents the physical device.

When the MIT report addressed the suitability of engineering faculties for the teaching of engineering design and the attitudes that make for successful designers, two telling comments opened the discussion: that "*embryo engineers should be taught by engineers*" and that "*the policy of recruiting our faculty primarily from newly made Ph.Ds and Sc.Ds leads to teaching analytical techniques to embryo analytical technicians.*"

Design in the 1990s

In 1961 the power of computers and the access to their use was quite limited. That changed at the end of the 1970s with the introduction of the personal computers and the minis and mainframes. This has accelerated at many engineering schools the process of making engineering more (quasi) scientific, through an even larger emphasis on mathematical and quantitative techniques.
In The Netherlands the undervalueing of design in applied engineering faculties, led to the initiatives to create two-year postgraduate designers courses at the three universities of technology. In many instances, the interpretation of design is limited to the application of (complex) analytical (mathematical) tools. The engineering design skills that are based upon the physical, visual, artistic and artisan experience play a minor role. It is often more-of-the-same curriculum that the designers already had during their graduate studies.
The special designers course does not solve the basic problem of the degradation of creative ('soft') engineering design within the curriculum of most of the engineering schools in the world, by the more prestigious 'number crunching' engineering sciences. The faculties should not take refuge in phantom solutions like more-of-the-same designers courses, but return to the basics of engineering, which has first of all to do with technology. This change will probably get very little support, as there are in general few qualified design engineers left in many faculties.

The problem of designing by numbers and formulas and losing touch with the physical reality of the design is reinforced by the myriad of software programmes. In naval architecture, the student just has to feed in the basic parameters of the ships, and OOPS! out comes the design, lines plan included. Or with CEM they get a thousand alternatives in a matter of hours. The chances are that the young engineers are numbed by these professional software programmes, and lose their feeling for design.

I strongly agree with prof. Ferguson that the balance in engineering education has tipped too much towards the abstract sciences and too little towards the design skills that are necessary to mould technology into new forms. I, myself, rely very much on the design-by-drawing method, before using more quantitative techniques. Although this book, is again an addition to 'rational' design process in shipping, it shows and underscores that the engineer's scope should be enlarged. By that I mean that the narrow perception of design within given technical parameters, should be broadened and include the full array of disciplines which make up the shipping, ship design and shipbuilding world. The students lack an all-round, holistic view of the world, and that problem gets worse due to the pressure to speed up the studies and to squeeze in yet another analytical science. The dominance of the brain over the intuitive, esthetic, artistic or whatever non-analytical human qualities, should be redressed.
In the words of Thomas Kuhn, the design engineering paradigm has to be changed within the engineering faculties. It is probably too late to achieve this,

but there are many signs that point in the direction that design gets a new leash on life. Concepts like business system engineering and concurrent engineering are new ways to organise and do design projects. These concepts are based on a much more comprehensive approach towards design, which business is forced to develop and adopt if it is to survive in view of the ever shortening product life cycles.
Therefore it is my conviction that these holistic design concepts will start to be picked up by the engineering schools, and will have an impact on the curriculum. This will mean a return - may be in ten years time - towards a better balance between science and technology.

CHAPTER 3: CURRENT DESIGN METHODOLOGIES IN SHIPPING

3.1 General structure of a design project

The most simple method a naval architect can use when he designs a new ship, is the *comparison ship method*. He searches for an existing ship that is almost identical to the ship he is designing, i.e., coefficients, dimensions and equipment. He copies this ship, and maybe adds a few minor modifications and improvements. Typical examples of this method are ships built in series like the Liberty, Victory and Freedom class ships. Due to experience with the previous ship, the new ship contains small modifications and improvements.
The advantages of this method are the accuracy concerning weights and prices, and experience with the performance of the previously built ships. Skills gained by the building of the previous ships make that the new ship can be built quicker and cheaper.
However, this method can only be used when there is extensive information available on the comparison ship. Often this is not so, e.g., when the comparison ship was built by another shipyard. Also, the newly designed ship must be almost identical to the existing one.
Because major improvements are very difficult to achieve by this method, deficiencies that are part of the previous ship are likely also to be part of the new ship too. Because of the small differences compared to the existing ship, this method can only lead to improvement innovations but not to basic or concept innovations.

Often the comparison ship method cannot be used. This is the case when the specifications for the new ship are different from the characteristics of existing ships. The same goes when there is a good existing comparison ship, but there are not enough data available.
Therefore most ships will be designed by an iterative method like the one described by the Society of Naval Architects and Marine Engineers in *"Principles of Naval Architecture"*. This method consists of a repetitive process. First a ship concept is composed. Then the characteristics like weights, hold capacities, stability and trim, main dimensions and coefficients, layout and propulsion are calculated. Finally, the calculated design is compared to the initial design demands and the ship configuration is adjusted accordingly. This process is repeated until the ship design meets the requirements of the client and classification societies. With every iteration the calculations and estimates become more accurate and the design more detailed. The iterations ensure a balanced solution.

Stian Erichsen in *"Management of marine Design"* distinguishes two types of iterations:

- *Iterations due to changes in the basis of the design;*
  The basis of the design comprises the definition of the problem and the assumptions, conditions and restrictions of the design. For obtaining a better design than previous ones, it is necessary to use ideas from other industries and technologies that may improve the design.
  New ideas and discoveries may change the initial assumptions and require redoing the design or parts of it. It is necessary to return to the stage in the design process where the initial assumptions and conditions were made and redo the design from that point on.

- *Balancing iterations;*
  Balancing iterations serve to find a balanced solution. Because many variables are dependant on each other it may be found necessary to carry out iterations to bring the variables into conformity. New results for a variable can allow more accurate calculation of other variables. For example, for a ship applies the following basic equation:

$$\Delta = Dwt + W_s$$

  Where:
  Δ = Displacement;
  Dwt = Deadweight;
  W_s = Light ship weight.

  The initial estimate of the light ship weight can be a percentage of the deadweight. From the deadweight and light ship weight the displacement can be calculated. When the displacement is known, the main dimensions of the ship can be determined. When these parameters have been decided, more accurate calculation methods, which require more information, can be used. On the basis of the new estimate of the light ship weight the new, more accurate displacement can be calculated.

The iterative process is graphically shown as a spiral, which is derived from *"The Principles of Naval Architecture"*, see **Figure 1**. Every circle represents an iteration in the design process. The spiral is followed through from the outside to the core, suggesting that the accuracy of the calculations and estimates increases during the design process. This method also allows for an innovative design process.

The Society of Naval Architects and Marine Engineers distinguishes four phases in the design of a ship:

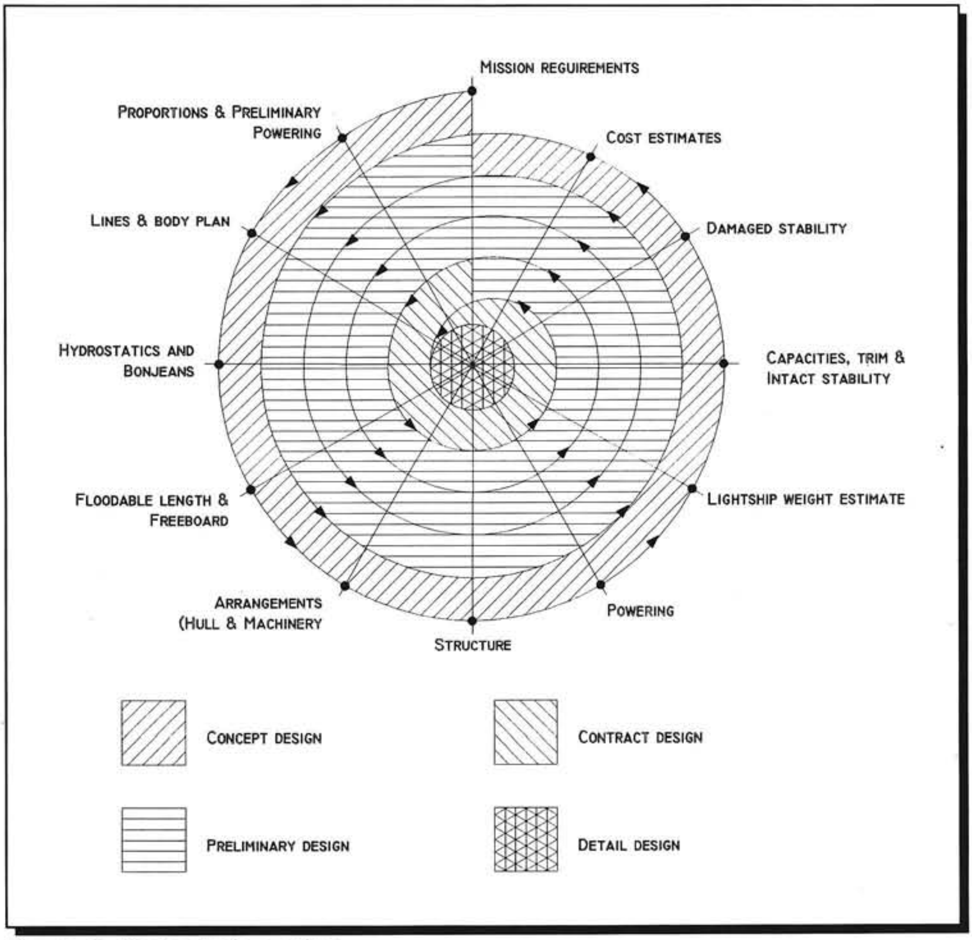


Figure 1: Basic design spiral

- *Concept design*;
  The concept design is the very first part of the design process where the shipowner's specifications are translated into naval architectural and engineering characteristics. The initial characteristics: length, breadth, draught, depth, block coefficient and power are determined. The preliminary light ship weight estimate plays an important role in this stage. It is usually derived from curves, formulas or experience.
- *Preliminary design*;
  In the preliminary design phase the major ship characteristics affecting costs and performance are determined. At the end of this phase, there is a precise definition of a vessel that meets the requirements and that is the basis for development of contract plans and specifications. This phase usually consists of several loops around the design spiral.

- *Contract design*;
  The contract design stage yields a set of plans and specifications that form an integral part of the shipbuilding contract document. It comprises one or more loops around the design spiral. It contains more precise features as hull form based on a faired set of lines, powering based on model testing, seakeeping and manoeuvering characteristics, the effect of number of propellers on hull form, structural details, use of different types of steel, spacing and types of frames.
- *Detail design*;
  The final stage of ship design process is the development of detailed working plans. These plans are the installation and construction instructions for the ship fitters, welders, outfitters and others.

3.2 Design methods

The design spiral is a generally valid method that enables the design of any type of ship and is therefore a good method to achieve a certain level of innovation in ship design. However, the results depend on the way the initial design is made. In theory it is possible to choose any ship configuration as a starting point, but because this is not very practical there are many methods to make the first conceptual design.
Four methods are discussed in this and in the following section. The last (fifth) one, is an addition to the present work practices within shipping and is discussed later. Its basic quality and strength is the explicit incorporation of performance indicators beyond the traditional ship design parameters in the design process. These performance indicators come from the broad range of shipping, and they are also the triggers for innovation in the basic ship concepts. Applying the Design Innovation in Shipping Methodology (DIS) will help the naval architect to structure the process of design, in particular at the concept level.
Besides the use of performance triggers, the method relies on the use of creativity methods, as does the Seakey method described in the next section. The objective of this book is to describe the DIS-methodology and illustrate its application with the help of case studies.

Three methods briefly described in this section are:

- Mathematical method;
- Coefficient method;
- Computer Exploration Models (CEM).

Mathematical method

The mathematical method describes all relations between the design parameters in equations. Therefore, this method is very simple to use in computer programmes. Starting with some initial input, a design is calculated according to fixed formulas and coefficients. Most computer programmes that use this method, contain some type of optimisation procedure that almost automatically guides the user to an 'optimum' design.
The advantage of this method is that it is very easy and quick to use. It can be used to make an initial design when there is not much time available for extensive calculations. By varying the input, different calculations can be made to determine the impact of parameter changes and a satisfying design can be found.
Disadvantages of this method are that ship design is a very complex process, which means many equations. Simplifying the equations affects the ultimate design in a negative way. The equations are composed for a specific ship type. For the coefficients fixed values, based on previously built ships, are chosen. This and the fact that the relations are fixed mean that this method is not suitable if one wishes to achieve major innovations in the ship design.

Example:

This example, based on *"Ontwerpen van schepen IV - Voorontwerp met Behulp van een P.C."* by H. van Keimpema, is a simple model for the design of an IMO-tanker and determines the initial values for the main dimensions. The model requires the following input:

- Deadweight (*DWTR*)
- Service speed (*V*)
- Service condition factor (*SER*)
- Propeller revolution per minute (*RPM*)
- Specific gravity of the cargo (*CSG*)
- Range (*Rad*)

The model uses a fixed draught and a fixed *L/B* ratio (*C2*), to prevent uncommon solutions. To start the calculation, the model requires two other coefficients:

- *Dwt/L*B*D* (*C1*)
- *D/T* (*C3*)

With the initial values and constants, the values of *L*, *B* and *D* are calculated according to the following formulas:

$$B = \sqrt{\frac{DWTR}{\frac{DWT}{L*B*D}*\frac{L}{B}*\frac{D}{T}*T}} = \sqrt{\frac{DWTR}{C1*C2*C3*T}}$$

where:

$L = B * C2$

$D = T * C3$

With the initial values the model calculates the deadweight (DWT) and the cargo tank volume (VOLCARA):

$$DWT = DISP - LSW$$

where:

$DISP = 1.03 * L * B * T * CB$ (Displacement)

$$CB = -0.132 * ArcTan(22 * \frac{0.5144 * V}{\sqrt{(10 * L)}} - 5) + 0.7$$

$LSW = WSTEEL + WOUT + WENG$ (Light ship weight)

$WSTEEL = WHULL + WPOOP + WFC + WDH$ (Weight steel)

- $WHULL$ = Weight hull
- $WPOOP$ = Weight poop
- WFC = Weight forecastle
- WDH = Weight deckhouse

$WOUT$ = Weight outfit

$WENG = WMOT + WREM$ (Weight machinery)

- $WMOT$ = Weight engine
- $WREM$ = Weight remainder

For the calculation of all separate weight items, estimate formulas are used. Together the weight items form the total light ship weight, and the available deadweight can be calculated. For example the Weight of the hull (WHULL) is calculated as follows:

$$4.04 * CX * Z^{0.65} * L * (1.108 - 0.016 * L) * \frac{22.8}{35.8 - \frac{L}{D}} * \frac{35.9}{14 + \frac{L}{D}} * (1.12 - 0.0163 * \frac{L}{D})$$

where:

CX = Correction coefficient

Z = Minimum hull midship section modulus about the transverse neutral axis

The required cargo tank volume is calculated as follows:

$$VOLLCARR = \frac{DWT - WSUP}{SG * 0.98}$$

where:

$WSUP = WHO + WDO + SLO + WFW$ (Weight supplies)

- WHO = Weight heavy fuel oil
- WDO = Weight diesel oil
- WLO = Weight lubrication oil
- WFW = Weight fresh water

SG = Specific Gravity

The available cargo tank volume is calculated as follows:

$$VOLCARA = VOLDT - VOLMK - VOLCOF - VOLSLOP - RBALCC$$

where:

$VOLDT = 0.98 * CBD * L * B * D$ (Hull volume up to the cargo deck)

- CBD = Block coefficient up to the deck

$VOLMK$ = Volume engine room

$VOLCOF$ = Volume cofferdam

$VOLSLOP$ = Volume slops tanks

$RBALCC$ = Volume ballast tanks

Again all weights and volumes are estimated by estimate formulas.

For a valid solution it is necessary that the following equations apply:

$$DWTR = DWT$$

$$VOLCARR = VOLCARA$$

To obtain a valid solution, a method is used that supposes a linear relation, between length, depth, deadweight and cargo volume. The above described design method is repeated for two other points, one with a different length and one with a different depth.

This results in three three-dimensional points (L_0, D_0, DWT), ($L_0 + \Delta L = L_1$, D_0 DWT) and ($D_0 + \Delta D = D_1$, L_0, DWT). Two three-dimensional lines are drawn, respectively through the points (LO, DO, DWT), (L1, DO, DWT) and (LO, DO,

DWT), (LO, D1, DWT). Now a new line is drawn between the intersections of the lines with respectively the x- and the y-axis. This line represents the relation DWTR = DWT (**Figure 2**).
The same procedure is carried out for the cargo tank volume (VOLCARR). Now both lines (DWTR = DWT and VOLCARR = VOLCARA) are copied to a two-dimensional graph. The intersection of these two lines gives the length and depth of the ship that has the required deadweight and the required cargo tank volume.

Coefficient method

When a naval architect wants to design a ship that is similar to existing ships, he can collect descriptions of similar, existing ships from publications or other sources. From these data he can compose diagrams with characteristics, coefficients and ratios. He has to ensure that the data from these reports are corrected for important differences in the design, e.g., extra cranes or ice class.
Some ratios and coefficients that can be used for this method are L/B, B/T, L/D, D/T, w_s, w_m, where L is the Length, B is the Breadth, T is the Draught, D is the Depth, w_s is the specific weight of the ship and w_m is the specific weight of the machinery. Coefficients from several ships can be put into diagrams and plotted against other characteristics. In these diagrams lines can be drawn, showing the relation between the plotted characteristics. These lines will show the average values. From these lines the values of the characteristics of the new design can be estimated.

This method is simple to use and the designer can carry out fast design calculations. The absolute results are not always reliable but the tendencies are sufficiently reliable. Many methods use coefficients as a basis for their calculations and estimates.
Disadvantages are that the validity is limited to the data of the comparison ships, which are the basis of the coefficients. Data are often retrieved from foreign sources and therefore uncertain. The coefficients are the average values from built ships. This again, limits innovations.

Example: Reefers

The starting point of the design is the ratio between the deadweight (dwt) and the displacement (Δ), which is the first coefficient:

$$C_1 = \frac{Dwt}{\Delta}$$

By choosing a C_1 (on the basis of experience or comparison with other ships) the ratio between dwt and Δ is known and the displacement can be calcuted. If the deadweight is required, e.g. the volume (reefers) or TEU-capacity (container

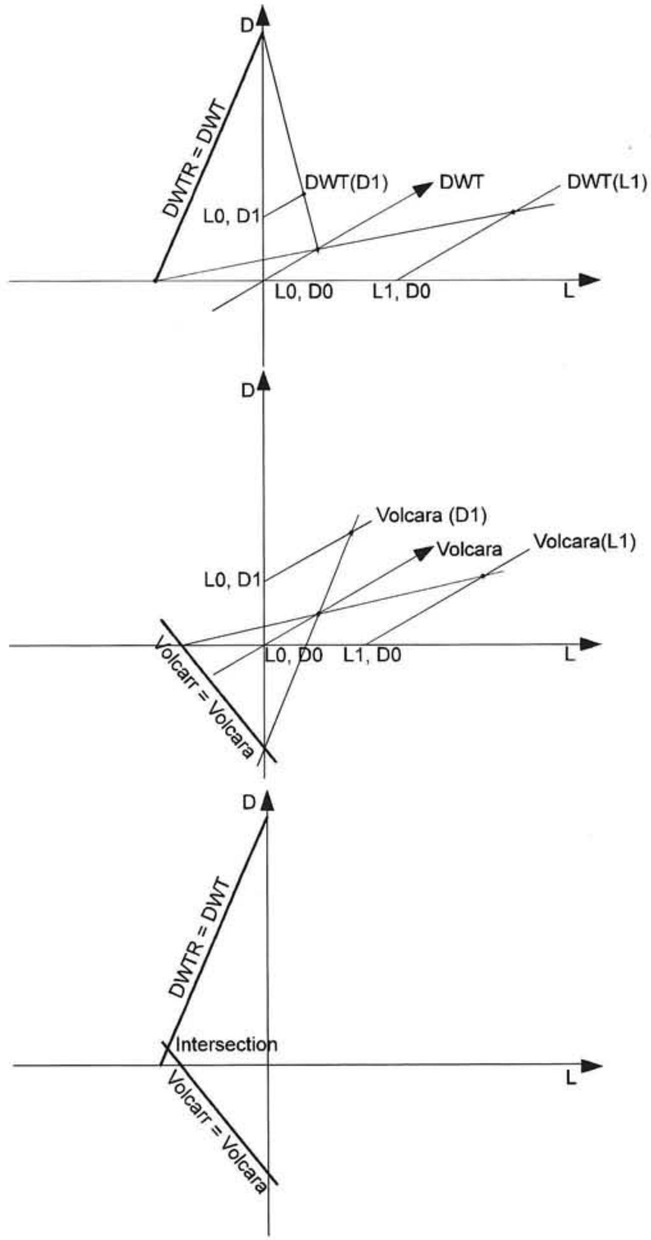


Figure 2: Calculation of the length and depth for the mathematical method

ships), it can be estimated by plotting the deadweight of other, comparable ships as a function of the volume or TEU-capacity, and estimating the corresponding deadweight for the capacity.

Then the length of the ship and the block coefficient are determined, in such a way that the length is as small as acceptable and the block coefficient is as large as possible from a hydronamical point of view.

$$L_{pp} = f(V, \Delta)$$

where:
V = Trial speed

The length can for example be determined from a diagram like **Figure 3**, in which the length is given as a function of the reefer capacity of a reefer. The data are derived from existing ships.

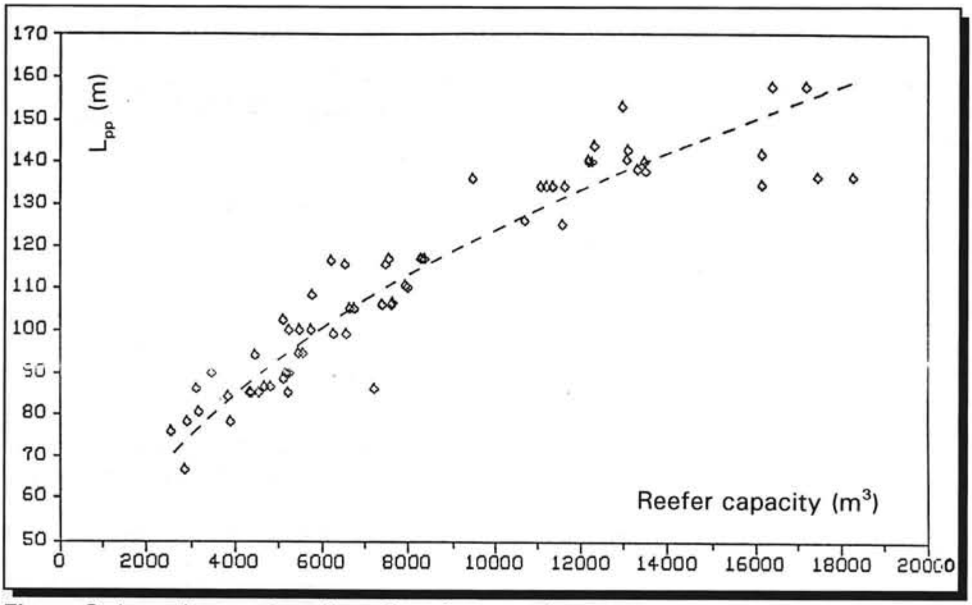


Figure 3: Length as a function of reefer capacity

The block coefficient can be estimated as a function of the coefficient V/√gL, which is the Froude number:

$$C_B = f\left(\frac{V}{\sqrt{g * L}}\right)$$

The underwater volume (∇) of the hull is:

$$\nabla = L * B * T * C_B$$

where:

$$\nabla = \frac{\Delta}{c_0 * \gamma}$$

where:
c_0 = Coefficient for the volume of hull and appendages
γ = Specific weight of (sea) water

Then the coefficient C_2 is chosen, where C_2 is:

$$C_2 = \frac{L}{B}$$

where:
B = Breadth

C_2 can be chosen from a diagram with L/B ratios from other, existing ships. The ratio has to be chosen in such a way that the stability and course stability are sufficient.

Now ∇ is:

$$\nabla = L * \frac{L}{C_2} * T * C_B$$

where:
T = Draught

Now T can be calculated. Subsequently the ratio D/T must be chosen, where D is the Depth. This ratio can again be chosen on the basis of existing ships.

The weight of the ship can be estimated, using the specific weight coefficient of the ship (w_s) and of the machinery (w_m):

$$w_s = \frac{W_s}{L * B * T}$$

and

$$w_m = \frac{W_m}{P_B}$$

where:

W_s = Weight ship
W_m = Weight machinery
P_B = Power of the engine

The total weight of the ship (W_{sm}) is:

$$W_{sm} = W_s + W_m$$

Other characteristics can also be estimated on the basis of coefficients. For example the volume of the hold:

$$\frac{V_H}{L * B * D}$$

where:

V_H = Volume hold

or the height of the centre of gravity,

$$\frac{KG}{D}$$

where:

KG = Height of the centre of gravity

Concept exploration model

Concept exploration model (CEM) is a computer oriented design method, which in contrast to most other computer methods does not use an optimisation routine. CEMs are specific for one ship type. Every ship type requires another model.

CEM consists of three phases: the pre-processor, the processor and the post-processor. In the pre-processor the user specifies ranges of main ship dimensions and parameters he wants to examine, e.g., a range of ship length, width, depth, draught and block coefficient, and a step size for each of these parameters.

For each discrete combination of values a design is produced by the processor. Also, economic parameters may be calculated. To limit computer time, the programme may reject solutions that do not comply with basic requirements like the metracentric height or minimum freeboard. The calculation procedures in CEM are for the greater part based on common procedures. These procedures generally make use of statistical data of previously built ships.

In the last part of the programme, the post-processor, the user can set boundaries to main dimensions and/or resulting parameters of the design such as deadweight, power, volume of holds and steel weight. Designs outside these boundaries are rejected, the remaining ones can be compared to each other and ranked by means of a merit function consisting of one or several parameters.

CEM can find the optimum design for a specific ship type, but only as far as this optimum can be determined by fixed equations and statistical data. Due to the large number of designs that is calculated, there is a good chance that the model finds a design that is better than the design the user would have found without this 'number crunching' method. Therefore, this method is an incentive for improvement innovation within certain restricted boundaries. Because a CEM is specific for every ship type, basic innovations are not possible.

Example:

This example is a short representation of the example in *"Concept Exploration Model for Multipurpose/container carriers"* by C. Georgescu, H. Boonstra and F. Verbaas. It concerns a CEM for multipurpose freighters. The assignment is to design a vessel with the following characteristics:

▸ Deadweight	6000	tonne, max. 6200 tonne
▸ Gross tonnage	≤ 4000	GT
▸ Cargo hold capacity	≥ 8000	m^3, max 8200 m^3
▸ Service speed	13	Knots for 15% sea margin
▸ Operating range	6000	nm.
▸ minimum freeboard excess	0.050	m.

The design is optimised on the relation between ship length and block coefficient. Initial values for the breadth and draught are kept constant. The exploration space is:

▸ Length	[95.00...105.00]	m., step 1.00m.
▸ Block coefficient	[0.68...0.75]	step 0.01
▸ Draught	[6.70...7.30]	m., step 0.02 m.
▸ Breadth	17.90	m.
▸ Depth	8.50	m.

The merit function for the evaluation of the designs is:

$$MF = wf1 * \frac{BC}{DWT} + wf2 * \frac{FOC * V_s}{DWT}$$

where:

BC	= Building costs in NLG
DWT	= Deadweight in tonne
FOC	= Daily fuel consumption in tonne
V_s	= Service speed in knots
wf1/2	= Weight factors

The results from the processor can be presented graphically. **Figure 4** shows iso-lines for *BC/Dwt* and *FOC* V_s/Dwt* for the relation L(m) and C_B. **Figure 5** shows the evaluation results of the merit functions for two different weighing factors for the relation L and C_B. The symbols have the following meaning:

- ● Generated and accepted designs;
- o Generated and rejected designs;
- ■ Optimum design.

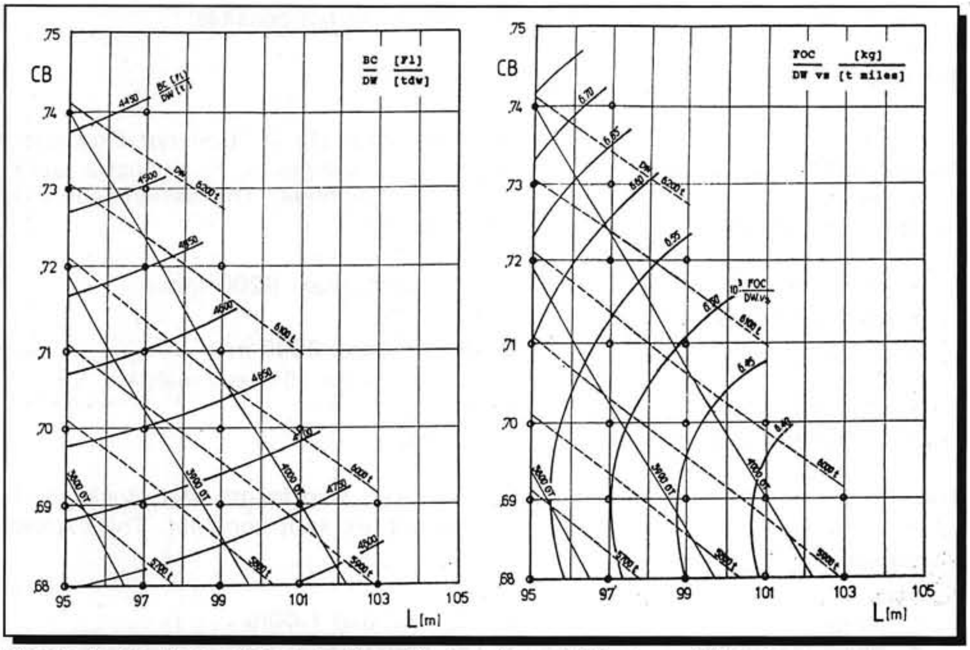


Figure 4: Iso-lines related to the ship length and block coefficient

The optimum (L, C_B) lies on the 4000 GT-line, limited by the 6000 tonne and 6200 tonne deadweight lines. The optimum moves depending on the weight factors, from - minimum L, maximum CB, corresponding to minimum specific building costs; to - maximum L, minimum CB, corresponding to minimum specific daily fuel consumption.

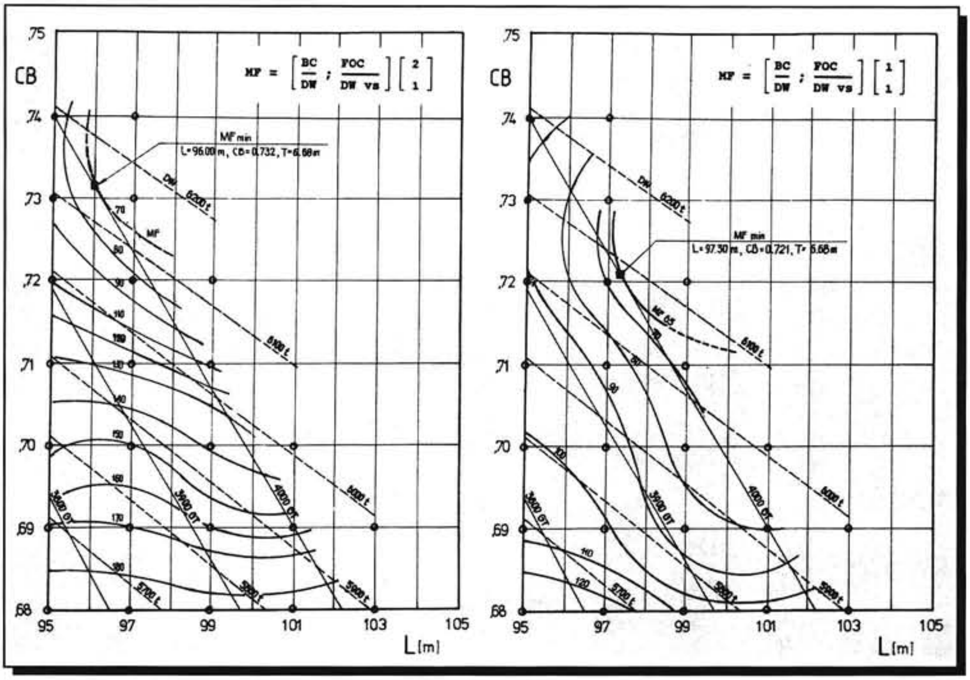


Figure 5: Merit function iso-lines for two different merit functions

3.3 Incorporation of innovation and creativity

The methods described in the previous sections are excellent for designing a new, reliable ship. However, they are not very well suited for the design of new ship types or achieving major innovations. That is why the Wärtsilä shipyard[2] developed the ***Seakey method*** described in *"Wärtsilä Seakey; Mission Based Ship Design"*, which considers the ship design from a quite different perspective.

The basic idea behind this method is that the shipbuilder and the shipowner put different demands on the ship design. Most shipbuilders build the ship to given specifications and consider the ship design as a collection of technical problems that need to be solved. For the shipbuilder the building cost versus price is most important. To get the order, the shipyard must convince the potential buyer about the economy of their ship, so the designer tries to reduce the costs.

[2]Kværner Masa Yards Technology, Turku, Finland

For the shipowner a ship is merely a way to get return on investment. His interest is: "*What kind of ship gives the best return?*" The ship should provide exactly the service the operator wants to give, but no more. The ship must be safe and built properly, and unnecessary costs must be avoided, but for the owner the return on investment is most important. Better than cutting costs is the increase of the ship's earning potential as a whole. Improving ships will therefore mean adapting them to the *needs of the market*.

The only possible way to achieve major improvements and innovations is to start the ship design from scratch. The computer based Seakey method starts from the very beginning, first defining the nature of the operation and then working out the best solution for the specific mission. The design is started from the very basic task the vessel is needed for.

The design is divided into four levels (**Figure 6**):

1. Mission;
2. System description;
3. Product design;
4. Component design;

On the *mission level* the basic business idea of the ship is decided. The definition starts with the transport demand and the total economy calculations. Based on the results, the route, the number of vessels and the operation schedule are decided.

On the *system level* all functions of the vessel are described. The system is divided into four main sectors - payload, crew, machinery and other spaces. For every sector the area, volume and weight are estimated and the result of this stage is a system description with the total area and volume needed in the vessel. The volume also gives an idea of the steel weight of the ship and by adding up the other weights, the first weight estimate of the vessel can be made. At this level of the design the vehicle does not even have to be an ordinary ship but could for example also be an airship or a submarine.

The *product level* starts by fitting a hull around the total volume and weight specified on the system level. Then the standard ship building routines for, e.g., power, hydrostatics and stability follow. The product level also includes the very first layout and geometric definitions.

After the product level the *component level* estimates the weight and centre of gravity by the sum of over 100 items. Seakey provides a standardised way to get a consistent weight and cost estimate. The user can either give exact component weights, if known, or predict the weight using a selectable reference ship and scaling functions. The result is an approximation of the weight, KG and LCG of the ship. If it differs too much from the initial estimate, the user may go

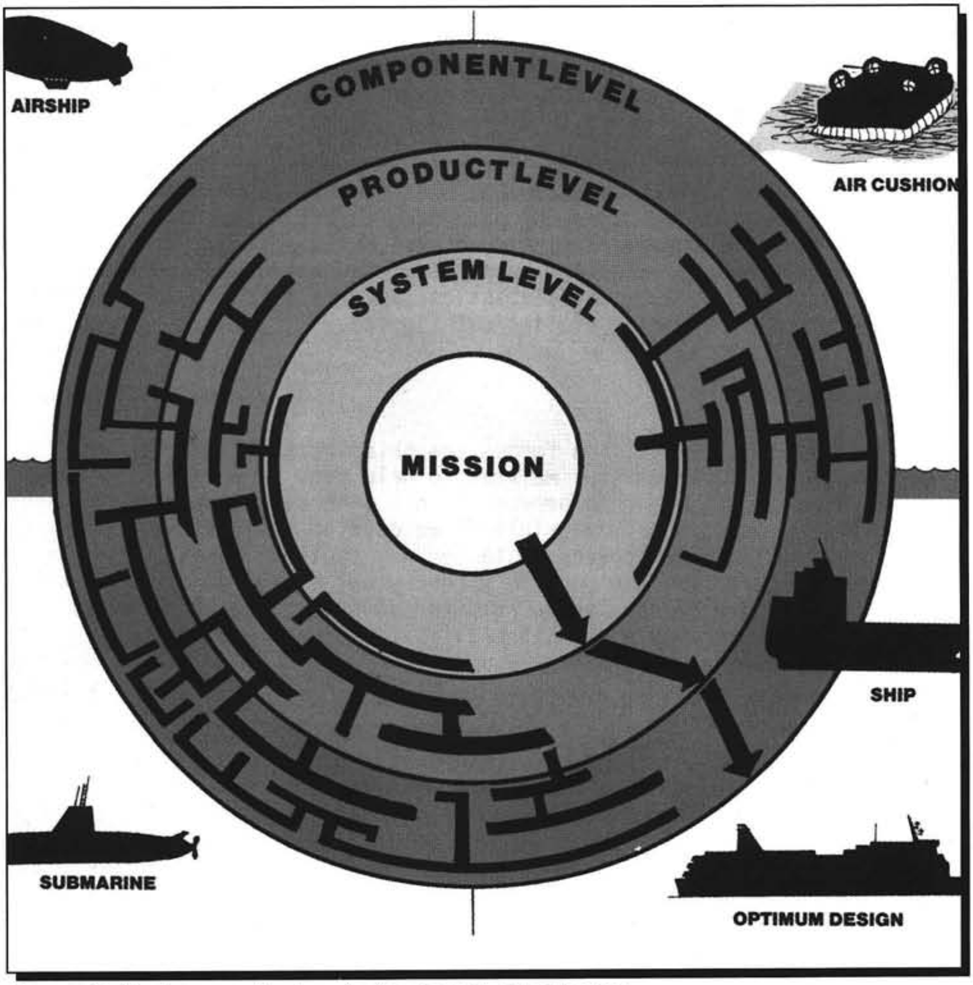


Figure 6: Seakey method; mission based ship design

back and redo the hydrostatic check or even change the main dimensions. The material cost and man hour of the ship are calculated using the same method and the same items as for the weight prediction.

During the design process with the Seakey programme there are special checkpoints where Seakey provides information to the user to help him decide how to continue. The user can also jump back and forth in the system, andmake changes at any point. This is important because of the iterative nature of the ship design.

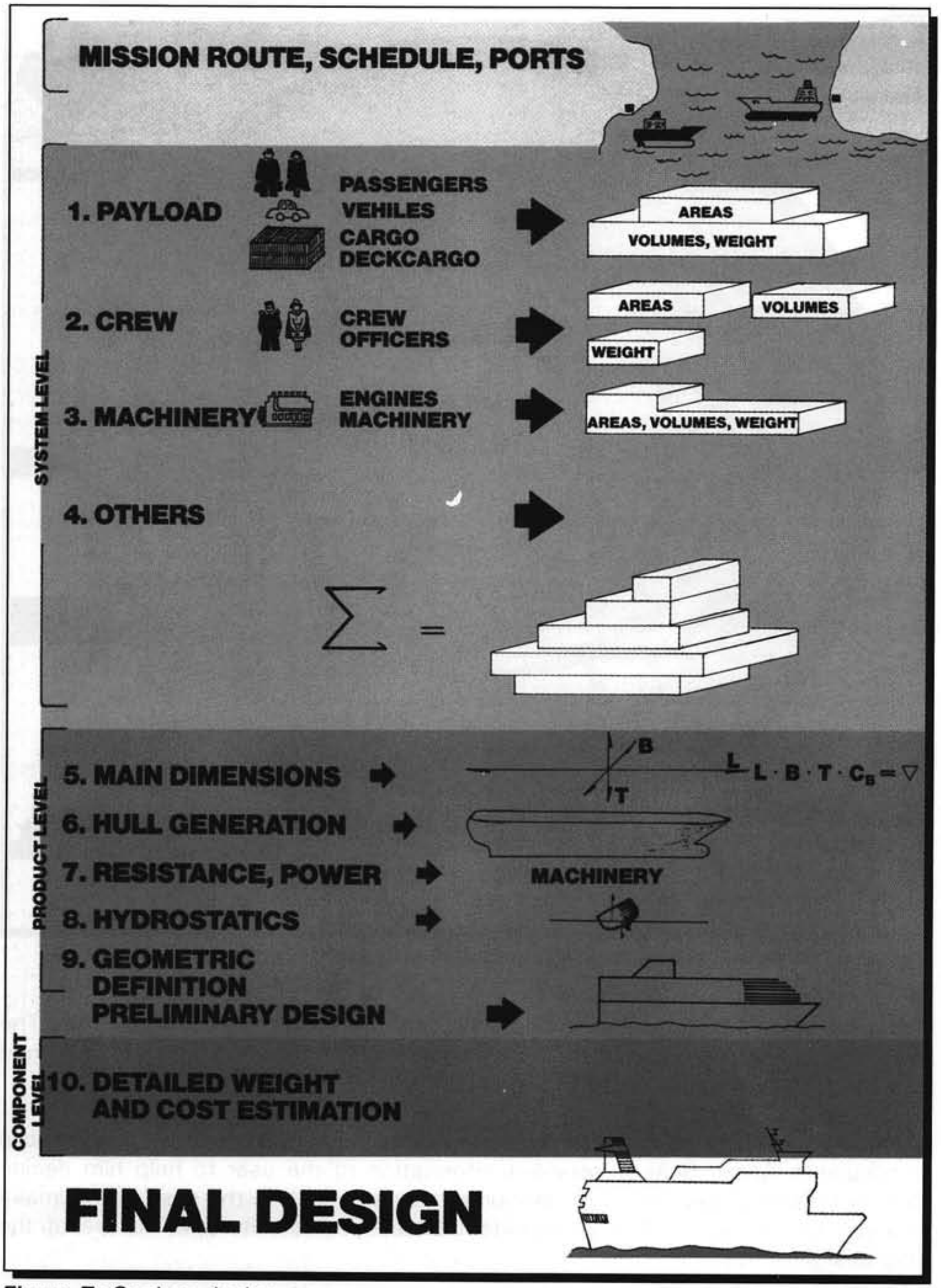


Figure 7: Seakey design process

Example:

This example concerns the design of a Superliner for the transatlantic route, a passenger ship that also transports containers. The target is to generate a passenger flow on the route between the U.S.A. and Europe that is large enough to employ at least two large passenger vessels on regular schedules. The ship should offer enough comfort and style for those passengers that have the money and time to spare. To be comfortable and safe the ship should be big. The extra volume will be used for containers. Transport of containers will contribute considerably to the ship's income. Container handling should not affect the external design and the port time of the vessel.
On the ***system level*** the areas, volumes and weights for all functions in the ship are estimated. All functions related to the payload make up the ***primary systems***. The payload of the Superliner consists of passengers, their private cars and containers. The input of the programme consists of the most important passenger spaces, the cabins. The number of cabins and for each different their type and size have to be entered. The total required area is calculated by the computer programme.

Further for the vehicles, the lane sizes, unit weights, number of units, and the free height of the vehicle deck has to be entered. All the three unit dimensions for the containers are required, as well as the unit weight and the number of units carried. Extra space required for deck cranes, storage racks, gangways and web frames is taken into account by the programme.

To handle the payload and to fulfil the mission of the ship, certain ***secondary systems*** are required on board. First the size of the crew must be established, dividing them into the deck, engine and hotel crew. Spaces for the crew are estimated in the same way as the passenger spaces.
The service functions are divided into catering, hotel and passenger service and are, e.g., the galley, laundry and hospital. The technical spaces are engine rooms, pump rooms, different types of tanks, casings, navigation spaces and mooring deck. For these spaces both the area and the volume are estimated, because normally these functions are located deep down in the ship where the shape of the hull considerably influences the layout.

Until now the design work took place on the system level. The results are summarised in the final description of primary and secondary systems. No decisions on the ship layout, main dimensions, etc. have been taken yet. Only a first estimate of the propulsion and auxiliary power has been used.
The final description of the internal spaces gives the areas and the volumes required for the payload, crew spaces, service spaces and technical spaces. It also lists all outdoor deck areas for passenger use, deck cargo and crew recreation, and technical decks as mooring areas.

On the basis of the volumes of the hull and superstructure, fairly accurate weight estimates of the steel structure can be made. Internal deck areas are used for calculating accommodation weights and weights of the comfort system. Type of machinery and its rating are used for the calculation of machinery weights and auxiliary power. The operating weight of the ship is the sum of the light ship weight and deadweight. Combined with the water density this gives the required displacement volume.

Now the design work continues with the ***product level***. Still any type of vehicle can be used, though only crafts supported by buoyancy forces on the sea surface are considered. This craft may, however, be an ordinary mono-hull or multi-hull ship.
First the main dimensions are selected. Statistics from previously built ships can be used as guidance. Then the hull geometry can be generated. The resistance and propulsion properties are calculated, first the resistance and effective power required for the desired speed, then the propeller diameter, number of propellers, pitch, etc. are chosen.

Now the rough drawings of a longitudinal section and a transverse section with the main dimensions, deck spacings and the superstructure and breadth are made. The geometric definition of the sketched layout is given to the computer separately for the hull and the superstructure. Deck height from base line is given with the aftmost and the foremost point of each deck.
The total deck area and volume available in the hull are calculated and the space required in the superstructure is calculated. The total area and volume in the hull and the superstructure can now be compared to the required values and if necessary a part of the design can be repeated.

On the ***component level*** the light ship weight is estimated more accurately. The weight can be entered or calculated using units and coefficients derived from statistical data or a reference ship. The longitudinal and vertical centres of gravity are estimated in the same way.
Material costs and man-hours are used to calculate the construction costs and the price of the vessel. The design process of the Superliner result in the ship as displayed in **Figure 8**.

Feasibility of the Superliner

For the transatlantic route a normal passenger ship will hardly be profitable. The extra cargo capacity from the Superliner may generate the necessary extra income that makes the venture profitable. The Superliner offers the shipowner a substantial extra income for only a small increase in investment.

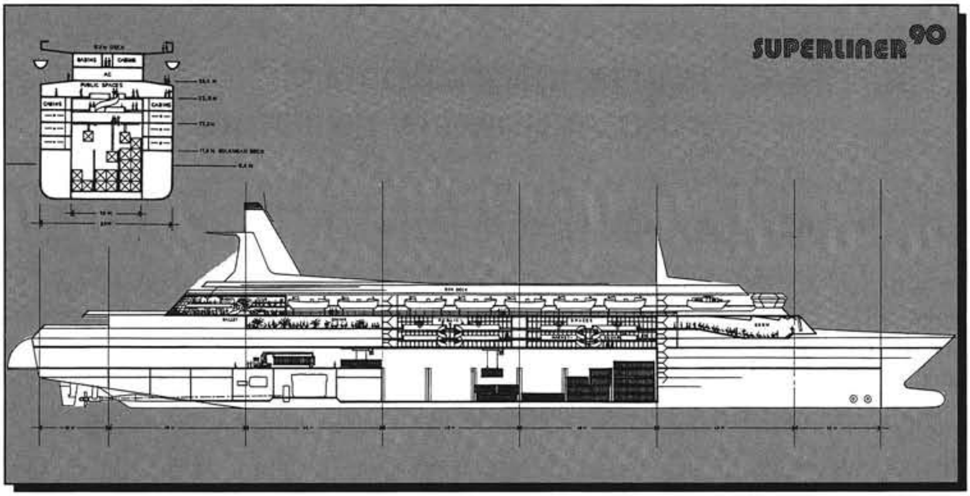


Figure 8: General arrangement of the superliner

The process and role of innovation

The modification of the design methodology requires a thourough understanding of the process of innovation in industry, shipping, but also in science. Underlying innovations are inventions. These themes will be discussed in the following chapters.

CHAPTER 4: INVENTIONS AND BASIC INNOVATIONS IN SHIPPING

4.1 Inventions in shipping: an overview

Inventions are the basic building blocks upon which innovations can be developed. There are many innovations in shipping, but a lot less basic innovations, which in turn are based on inventions. This chapter explores some of the historic developments behind inventions in shipping, or inventions that impacted shipbuilding and shipping indirectly.

The development of sea transport has been quite different from that of land transport, which evolved (apart form the wheel and the horse) little if at all until the invention of railways and later the motorcar. In contrast, sea transport developed steadily and surely. Boats became bigger and faster, they could carry heavier loads and travel longer distances. This type of development was made possible by several factors.
The sea is a universal road, so no road-building was required, while a source of energy was available in the wind. Because a boat is supported by the water, it was possible to build bigger and bigger boats without encountering the problems of support and friction that would have occurred in land transport. Finally, an excellent raw material, wood, was readily available and easily worked.

From coracles made of a wooden framework covered with skins or tarred cloth to large galleons sailing the Atlantic, the process seems to have been smooth. Although sails were obviously better for long distances, they did not have the control and manoeuvrability of oars; so for naval warfare the development of oars continued alongside that of sail. Different types and rigs of sail were developed, some making it possible to sail into the wind or closer to the wind, others giving better directional control. Although these differences may appear small, in practice they would be very important.
Figure 1 shows the evolution of speed of sailing vessels in relation to the wind force. It is evident from this graph that the iron hull vessels could increase their speed by increasing the number of masts that could carry sails. The maximum number of masts was usually five, due to restrictions imposed by the ship's stability. The ultimate effort of the shipowners, who did not believe in steam engines on board ships, was the construction of the 7-mast *Thomas W. Lawson* (**Figure 2**). This ship was built in 1902, when steamships already had become the dominent ship type, perished in 1907 in storm, while at anchor in a harbour. The ship had become too instable and tipped over in a storm. This marked the end of the sailing era.

Sailing Ship Evolution of Speed (knots)												
Wind Force (Beauforts)		1	2	3	4	5	6	7	8	9	10	11
around 1850		1	2,5	4	5,5	7,5	9	9	<9	-	-	-
Wooden vessels	1875 - 1900	1,9	3,2	4,7	6,1	7,5	8,6	9	9,3	9	8,3	-
Metal vessels	3 masts	2,1	3,2	5	6,7	8,1	9,3	9,9	9,7	9,6	8,7	-
	4 masts	2,2	3,5	5,7	7	8,8	10	10,7	11	10,8	9,5	8,3
	5 masts	2.6	4.2	6,5	9,1	10,8	11,9	13,1	13,4	13,3	12,7	12,2

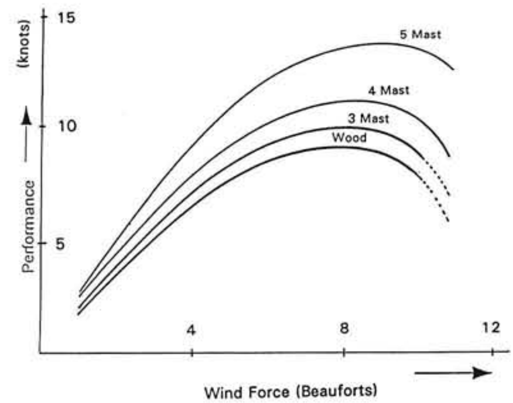


Figure 1: Evolution of speed of sailing vessels

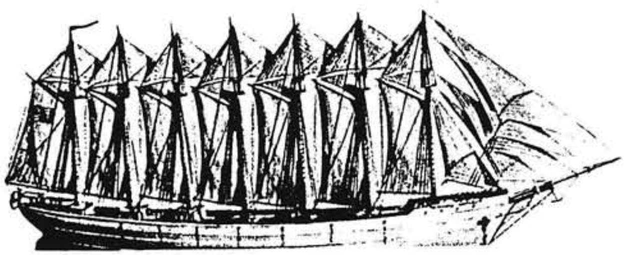


Figure 2: 7-mast *Thomas W. Lawson*

The improvement in efficiency of the sailing ships as from around the year 1600 can be represented in an S-curve, which is shown in **Figure 3**. It could start with the design and construction of the Dutch Fluit, a unique ship of 160 tonnes, which could be sailed by a 7 men crew (compared to 30 for traditional ships), and the length to breadth ratio was more favourable, which gave it a good sailing performance, especially for ships with a shallow draught, as was required to enter the Dutch ports at that time. The sides were also vertical, which facilitated the stowage of cargo (**Figure 4**).

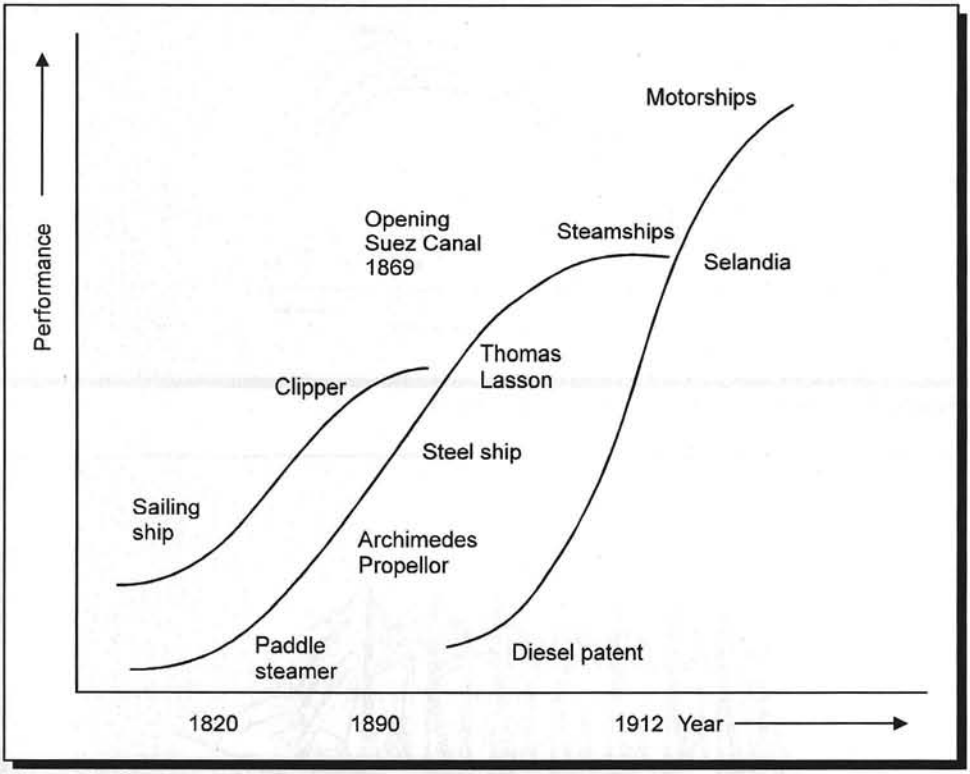


Figure 3: S-curve of improvement in efficiency of ships

The competitive advantage created by this ship type, lay at the basis of the Dutch supremacy in shortsea trades in the decades thereafter.
The curve ends with the clipper, the superb sailing machine, with it unique design features. This fast ship created a whole new market for itself, because of the phenomenal speed (if the wind was blowing). **Figure 5** shows an example of the clipper ship type.

Paddle wheels are a natural extension of human-powered oars or the water-wheel. As early as the Romans, at least the idea of a paddle boat powered by oxen seems to have occurred. When the steam engine was invented in 1712, it appeared obvious that it should be put into a boat to drive paddle wheels.

Figure 4: The fluit

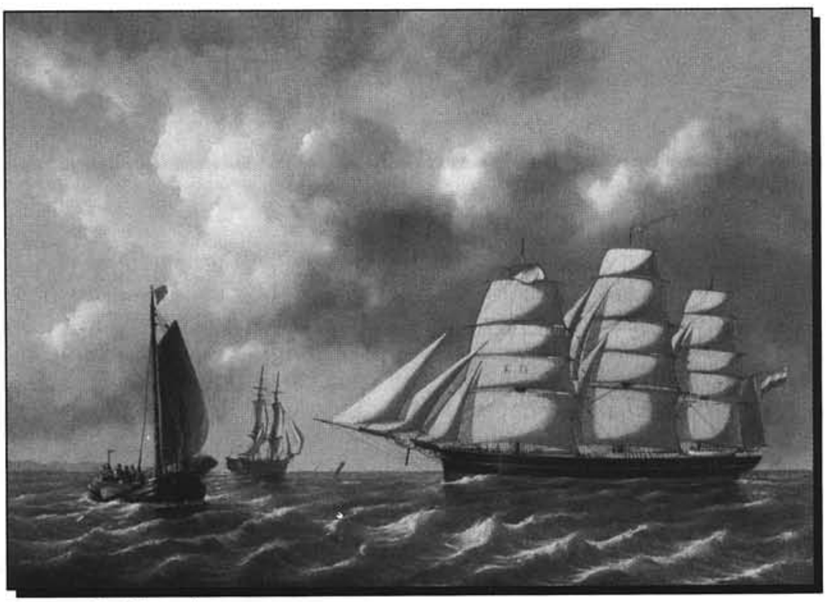


Figure 5: The clipper

This was first done for boats that were to use canals or rivers. On such waterways the paddle boat would have an immediate advantage over the sail boat, which could not operate in a narrow waterway. It was only when the technology had been thoroughly worked out and when the condenser made unnecessary a continuous supply of fresh water that the paddle boat moved out to sea (**Figure 6**).

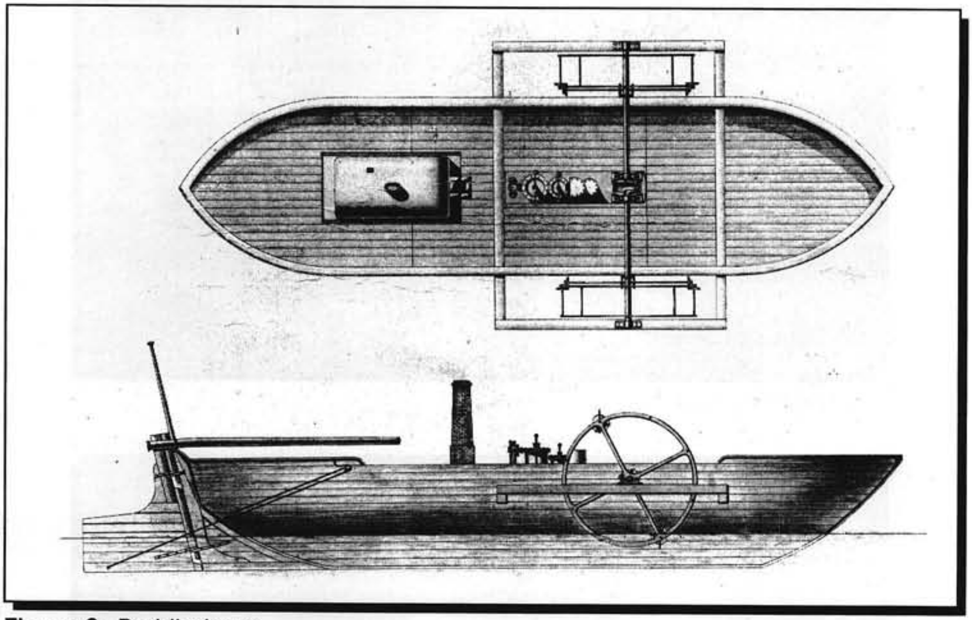


Figure 6: Paddle boat

As so often, the next development was aided by war technology. Paddle boats are not suitable for warships, because a single shot can wreck a paddle and render the boat useless. A screw propeller, being submerged and in any case very much smaller, does not have this disadvantage. Warships driven by screw propellers were first used in the American Civil War with some success. But the British Admiralty remained doubtful. So a classic tug-of-war was arranged between a paddle boat and a screw boat, and the screw boat pulled the paddle boat backwards through the water. Very rarely is there such an opportunity of a new invention.

Once the screw was established, ships continued to increase in size. Developments in engines and shipbuilding technology made this possible. After the steam-driven ships, came the steam turbine, followed by the diesel engine and the gas turbine. The efficiency increase created by the shift from sail to steam ships was impressive. A cargo steamer would cost twice the price of a clipper of the 1860s but it could carry four times as much cargo at three times the average speed.

An important improvement in navigation became possible through the development of the sextant and the marine chronometer, whose swing of the pendulum would not be affected by the movement of the ship in rough water. Radar had a different origin, but its application in shipping has vastly improved the safety of navigation. Refrigeration was invented in 1834 and the concept was in an early stage applied to ships (**Figure 7**)

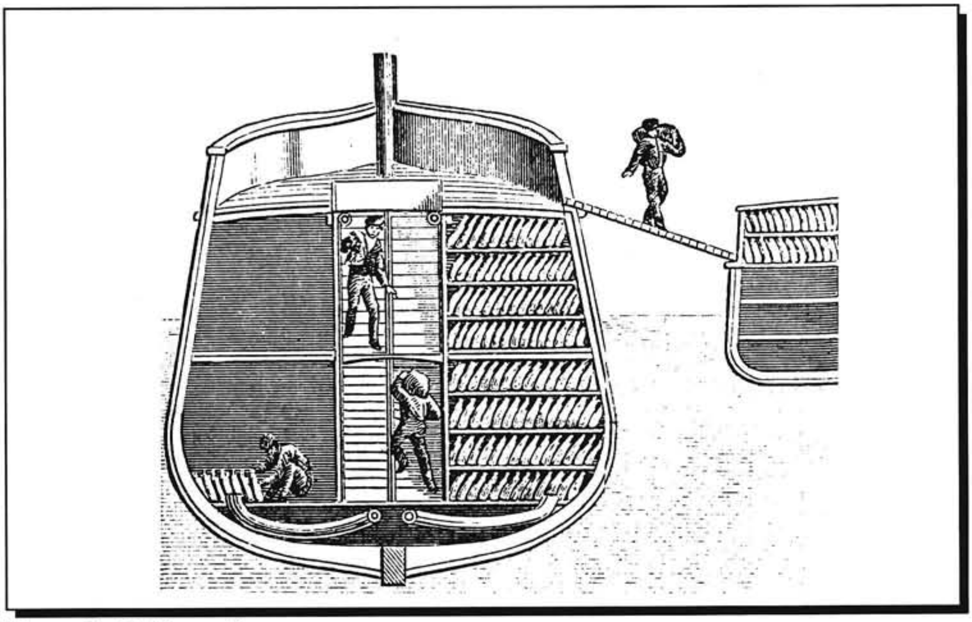


Figure 7: Refrigeration

The basic principles of propulsion remained basically the same for many decades, although the principle of dynamic lift, which led to the development of the hydrofoil, was already invented in the middle of the 19th century. Another invention was the hovercraft, based on the helicopter principle of powered lift. These abovementioned developments are briefly described in the following paragraphs.

4.2 Inventions in shipping

The following extracts are taken from the book *"Eureka"*, by E. De Bono (ed.). This excellent book contains many more examples of inventions, and the reader is adviced to look it up in the library.

Steamship

The search for a mechanised alternative to sail at sea began in Rome a millennium and a half ago. A low relief cut in the year 527 shows a Roman warship with six primitive paddle-wheels driven by oxen. More than a thousand years later Denis Papin, a Frenchman, developed a concept for a vessel driven by steam. A hundred years later another Frenchman, Perier, built a boat that moved experimentally on the Seine. Yet the germinal steamship was built by an Edinburgh banker, Patrick Miller, an eighteenth-century dilettante of science, on the Loch of Dalswinton in the deep valley northwest of Dumfries. Powered by an engine built by William Symington, it made a speed of five knots on its first passage.
The succession is singularly clear. Miller, having fathered his steamboat, lost interest. Symington determined to perfect it. He found a patron in the Dundas family and designed a boat that he called the *Charlotte Dundas* to haul barges on the Forth and Clyde Canal. Too successful, the Charlotte Dundas threatened to bring down the banks of the canal, and was abandoned. But Robert Fulton, an American jeweler, artist and engineer, came to Scotland to see it, was inspired, and went to Paris in 1803 to build a version of his own. Barely four years later he set up a steam packet line on the Hudson between New York and Albany. (**Figure 8**)

It needed, however, the invention of a surface condenser in 1830 to solve the problem of freshwater for the boilers and take the steamship to sea as an economic proposition. The ship *Savannah*, using an auxiliary engine for the part of the passage, crossed from New York to Ireland in 1818, the Dover-built *Calpe* crossed in 1827, and the *Royal William* six years later; but it was the tiny cross-Channel vessel *Sirius* that made the first passage under steam alone in 1838.
Even after the *Sirius*, two fresh advances in technology were essential before victory was complete - the iron hull and the screw propeller. The Aaron Manby, backed by another Dundas and 'Mad Charlie' Napier, proved the feasibility of the first. The *Francis B. Ogden*, built by Ericsson on the Thames and rejected after trials by a purblind Admiralty, provided the second. In 1843 all three things were combined in Brunel's *Great Britain* - salvaged in the Falkland Islands to be brought back to her home port of Bristol. (**Figure 9**)

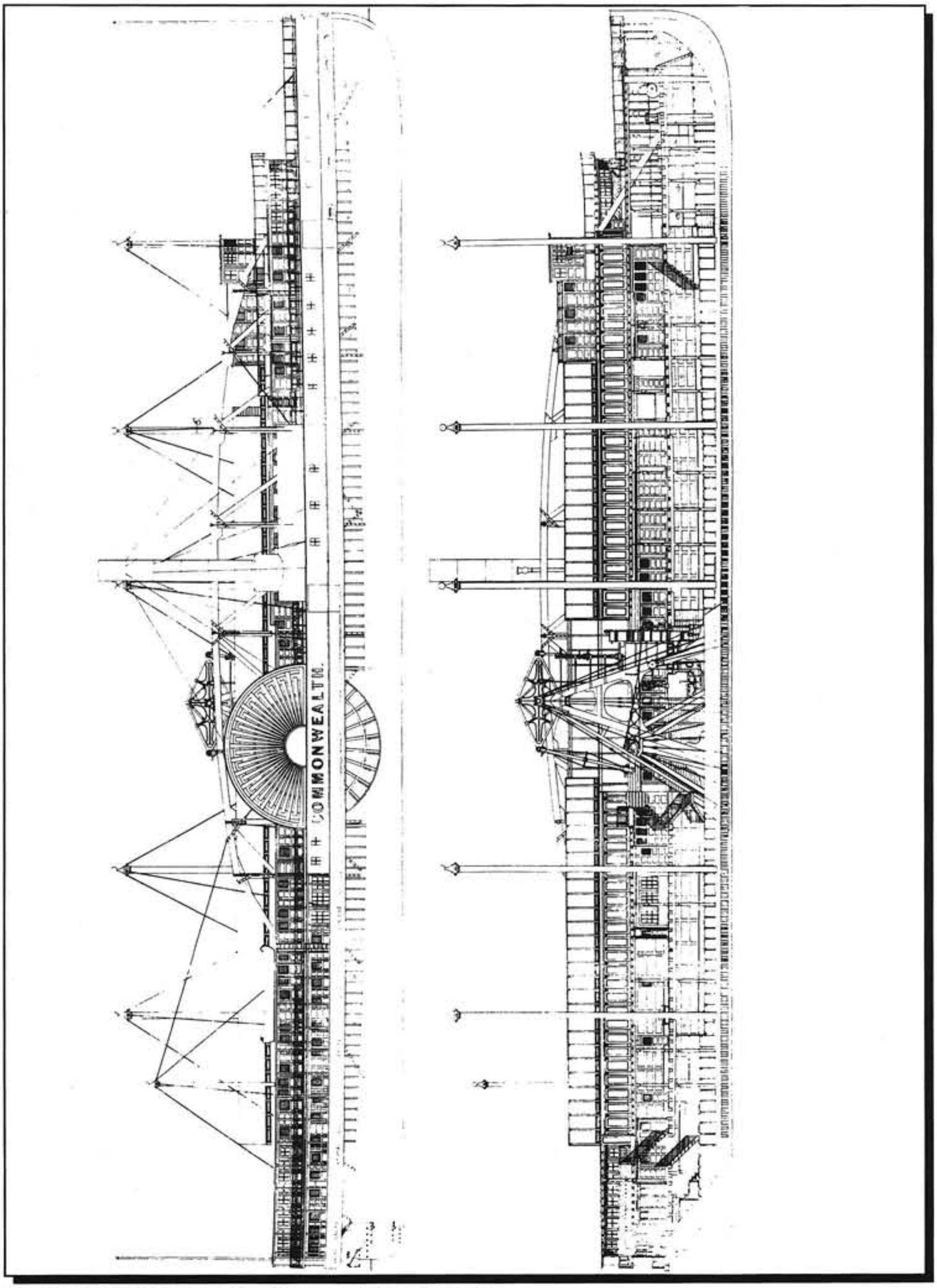


Figure 8: Steam packet line on the Hudson

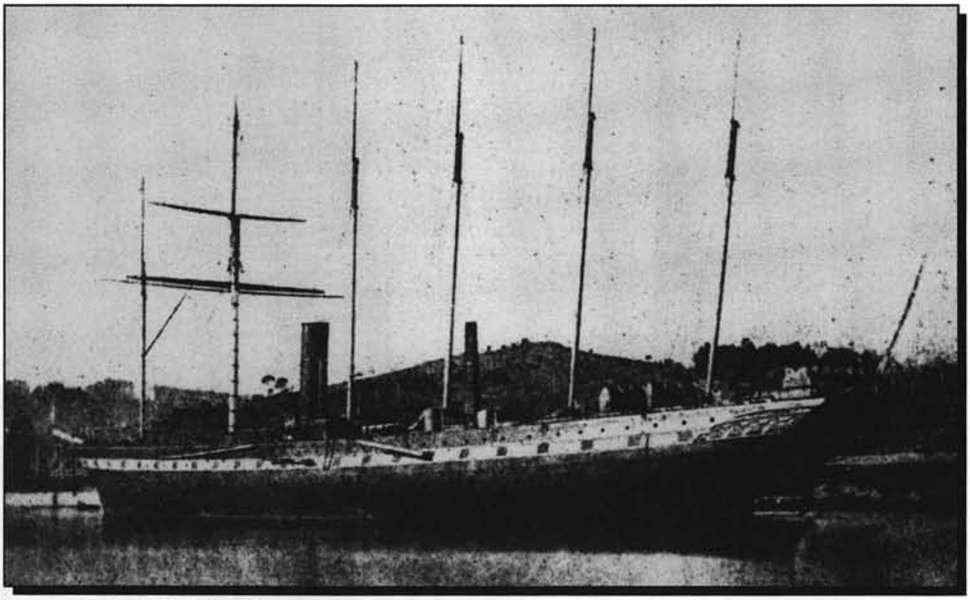


Figure 9: *Great Britain*

What was the impact of the steamship on the sea world? The answer is complex. The short version is that it shrank by more than a half, perhaps by as much as two-thirds; it eliminated dependence on the trade winds; it cut the seasons out of sailing. Only spherical trigonometry can compute its impact precisely but it can be illustrated by the practice of the East India Company, reckoned on a minimum of a year for a round voyage to Bombay; eighteen months was acceptable. A *Great Britain* at an average speed of 9.3 knots, with three coalings stops and an allowance for head winds, could have made three trips in eighteen months. From this kind of blunt fact developed the *Great Eastern,* the *Mauritania*, the *Queen Elizabeth* and the half-million ton tanker.

Screw propeller

Steam power was shown to be practical for navigation in the first decade of the nineteenth century. Experiments had been made in the last half of the eighteenth century, and three methods of propulsion by steam power were advocated and tested: paddles, jet propulsion and the screw.

In 1775 Benjamin Franklin saw that paddles would be inefficient, and suggested jet propulsion by a pump sucking in water at the bow of a vessel and forcing it out at the stern. In 1782 such a boat was tried on the Potomac, and as late as 1865 the Royal Navy built an armoured sloop, the *Waerwitch,* propelled in this manner.

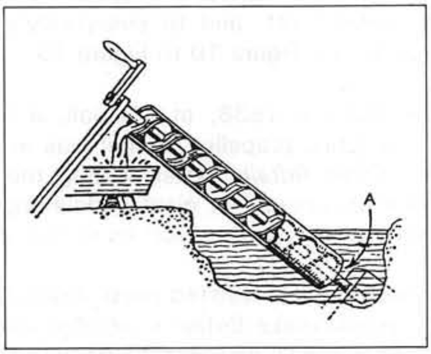
In 1837 Sir Francis Pettit Smith (1808-1874) experimented with his first screw-propelled steam launch; Captain John Ericsson, Swedish ex-army officer - later to become noted as an inventor and to build the famous screw-driven *Monitor* - was experimenting at about the same time. Pettit Smith's propeller was of wood; on the trials about half of it was broken off, and to everybody's astonishment this materially increased the speed, see **Figure 10** to **Figure 13**.

Encouraged, he built the *Archimedes*, launched in 1838, at Millwall, a three masted schooner fitted with an engine and a screw propeller. Brunel was at that time building the enormous iron ship the *Great Britain*. After testing the *Archimedes*, he scrapped his plans, already far advanced, for giant paddle-engines in the *Great Britain*, and substituted a huge propeller, with which he successfully crossed the Atlantic in 1845.
Brunel tried to persuade a reluctant Admiralty (which resisted most innovations at this time, fearing that a naval arms race would make Britain's wooden men of war obsolete) to equip a screw propelled fleet. Paddle-powered battleships were out of the question - shot and shell would quickly smash paddle wheels and put the ships out of action.
Smaller naval vessels, however, were being powered by steam. Paddle-tugs were used at the Crimea to tow battleships. In 1841, Brunel got the Admiralty to agree to experiments. An 888-tonne sloop, the *Rattler*, then being built at Sheerness was adapted for propeller drive, and matched with a comparable paddle-sloop, the *Alecto*. Among other tests, there was a tug-of-war, which ended with the *Rattler* dragging the *Alecto* after her at 2.8 knots. This was conclusive.
Propellers needed a higher speed of rotation than the paddle-shaft; until engine speeds improved, geared drives using ropes, pitch-chains or tooth-wheels were used. The *Great Britain* used pitch chains. Although Brunel's next ship, the gigantic *Great Eastern* used paddles as well as a propeller, by the end of the 1860s the propeller had triumphed.

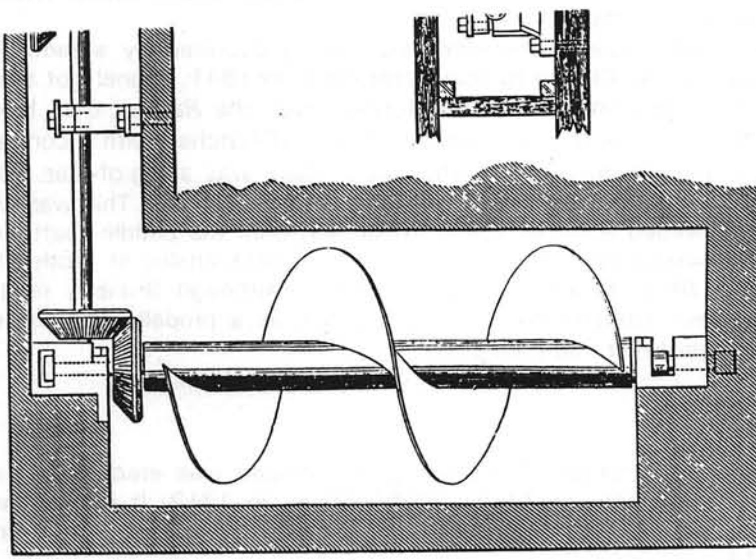
Steam Engine

The world's first practical working steam engine was erected by its inventor, Thomas Newcomen, at Tipton, Staffordshire, in 1712. It pumped water from the workings at the Earl of Dudley's Coneygre Colliery for more than 30 years **Figure 14**.

Thomas Newcomen was a Dartmouth ironmonger, familiar with the tin mines of Devon and Cornwall and with their besetting problem - how to remove the water from their ever-deepening levels. Newcomen determined to find a solution, but it took him 10 years of experiment before he arrived at a satisfactory answer. And even then his engine was unacceptable to the Cornish miners because it had a voracious appetite for coal, which they had to import by sea at great cost. It was the mine-owners of the Midlands who, faced with similar water problems, became the first users of Newcomen's steam engine.



Archimedean screw pump: 'A' is the opening for the entry of the water.



The original form of Smith's propeller and its position in the deadwood, from the first Patent drawings.

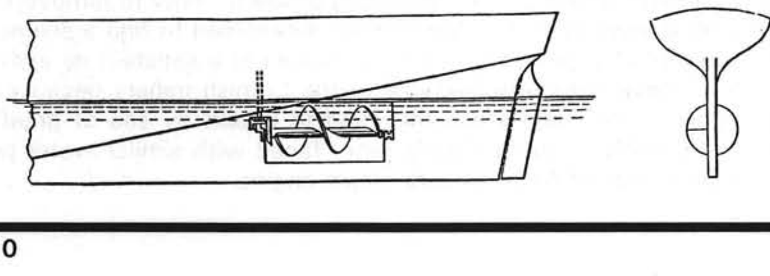
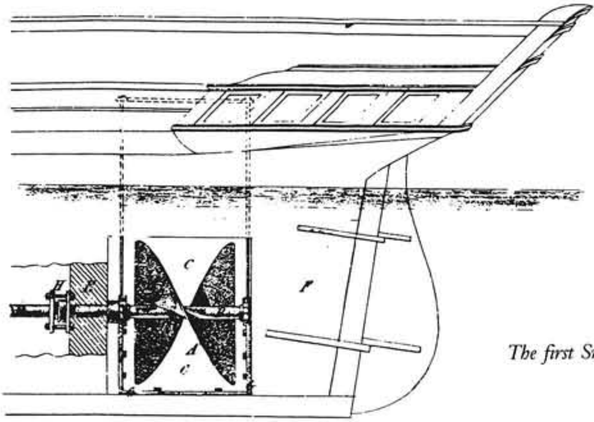
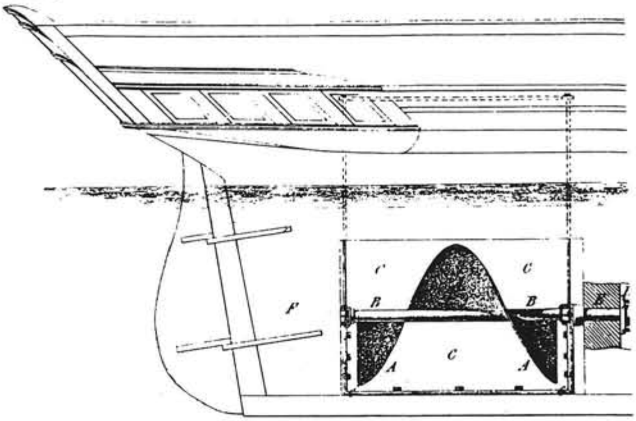
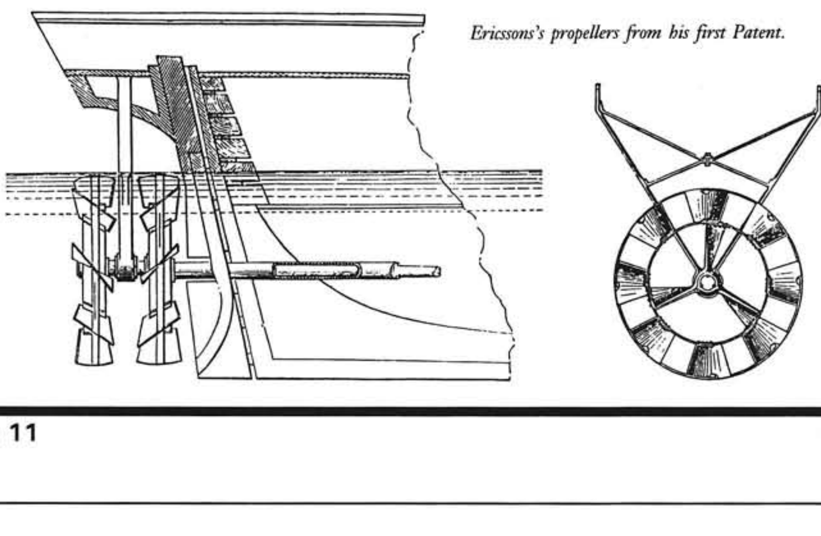


Figure 10



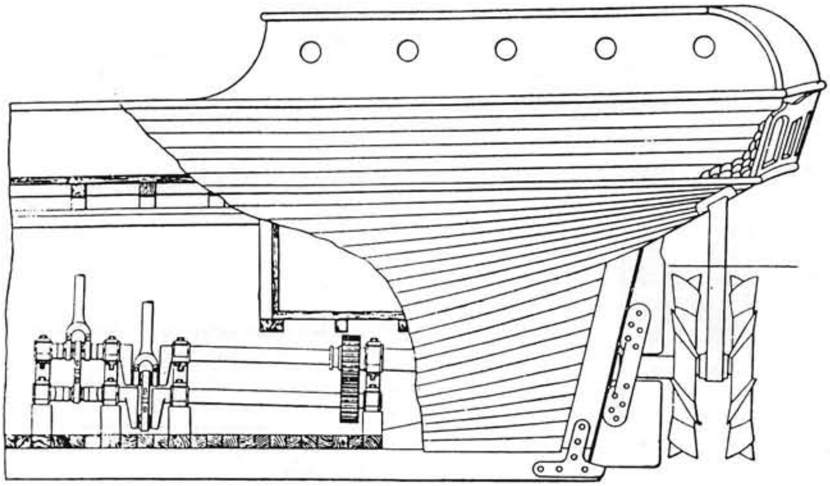
The first Smith screws fitted to Archimedes.



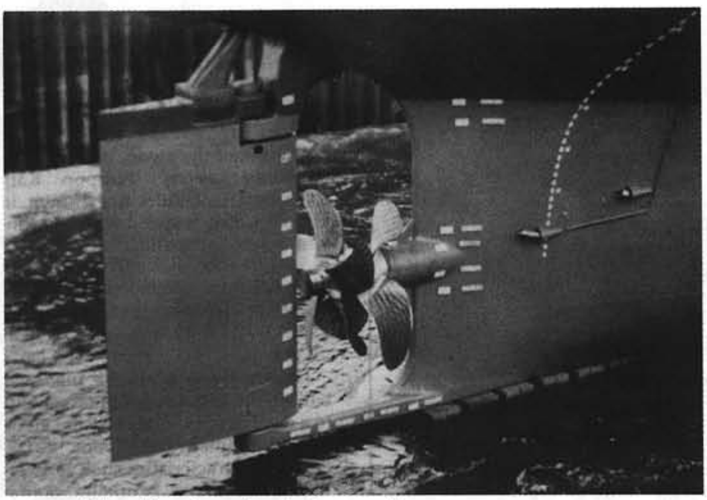


Ericssons's propellers from his first Patent.

Figure 11



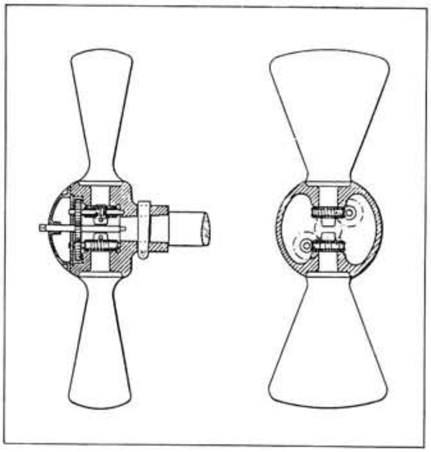
Ericssons's double screws as probably first fitted to the Robert F Stockton.

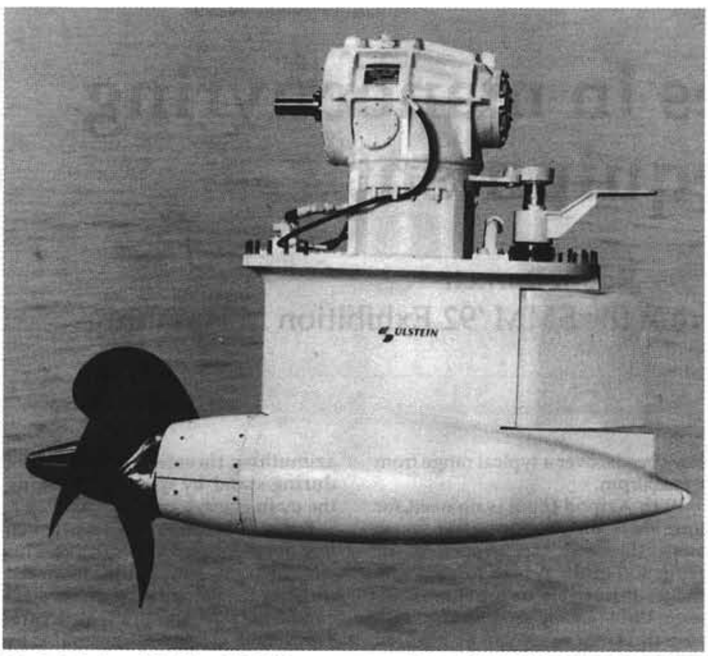


View of Juno's *contra-rotating propellers.*

Figure 12

Woodcroft's adjustable blades: a practicable controllable pitch propeller.





Fixed pitch Speed-Z-drive FPZ 47 (power range: 600 to 1030kW [816 to 1400hp]).

Figure 13

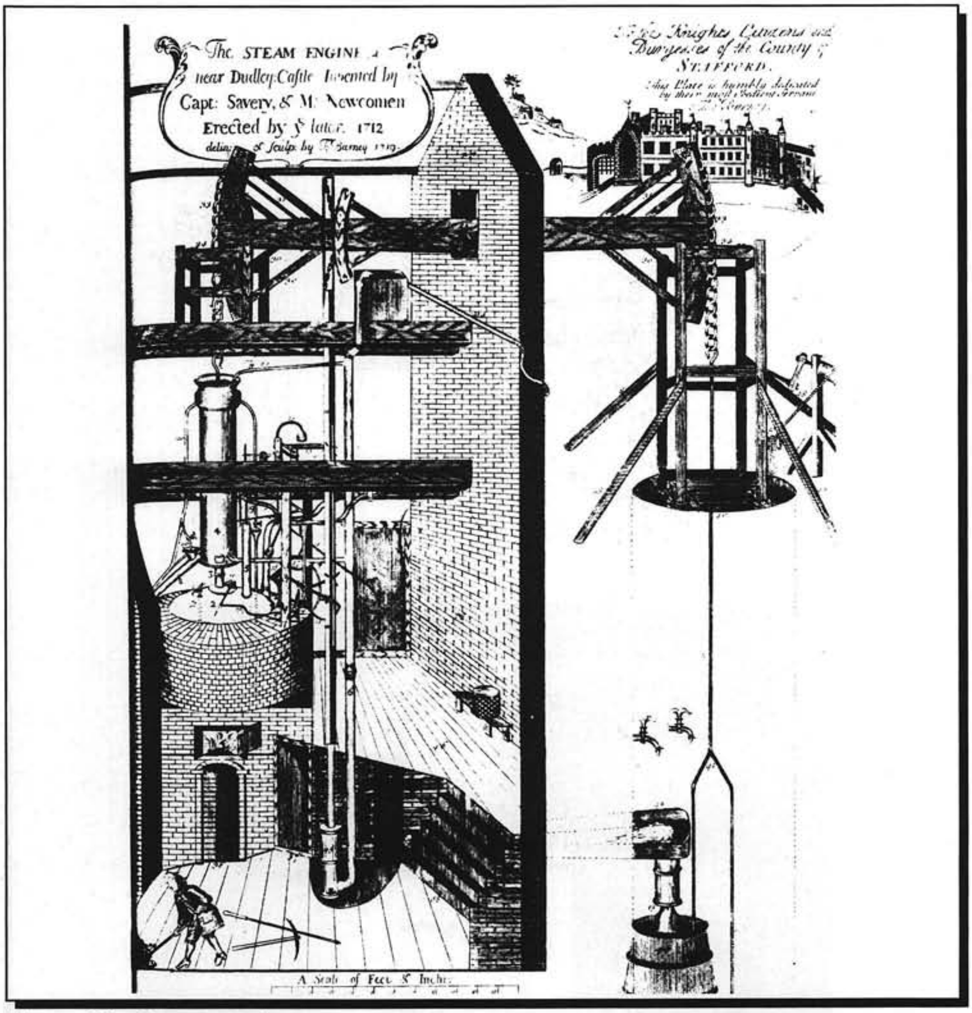


Figure 14: Steam engine

The vertical cylinder of the engine was open at the top and the piston-rod was linked by chains to one end of a pivoted wooden beam. The pump-rod was connected by chains to the other end of the same beam. As the pump-rod descended, its weight drew the piston up the cylinder. At the same time a valve opened to fill the cylinder, below the piston, with steam from the boiler. When the piston reached the top, the steam supply was cut off and a second valve opened to admit a jet of cold water. Condensing the steam created a vacuum in the cylinder and caused the piston to be driven down again by the atmospheric pressure on its upper surface. This power stroke raised the pump-rods and so lifted water out of the mine.

Strictly speaking, Newcomen's invention was an 'atmospheric engine', using steam merely as a convenient way of forming a vacuum. Nevertheless, he was the first man to harness power successfully by means of a piston in a cylinder, and his engine of 1712 was the undoubted parent of all subsequent machines of this type. And it played a vital part in Britain's Industrial Revolution by enabling more coal to be mined from deeper levels.

James Watt dit not 'invent' the steam engine as is commonly supposed. What he achieved was a great improvement in efficiency by condensing the steam in a separate closed vessel instead of the cylinder itself. He also closed the top of the cylinder and used low-pressure steam instead of cold air to drive the piston down. This improved engine of Watt still depended on the creation of a vacuum and used steam at extremely low pressure. It could not be otherwise when boilers were little better than brewer's coppers, unable to withstand high pressures (**Figure 15**).
The Cornisham Richard Trevithick was the first to harness 'strong steam', as it was then called. Yet the Cornish beam engine, which was the outcome of this third stage of development, still closely resembled Newcomen's engine.

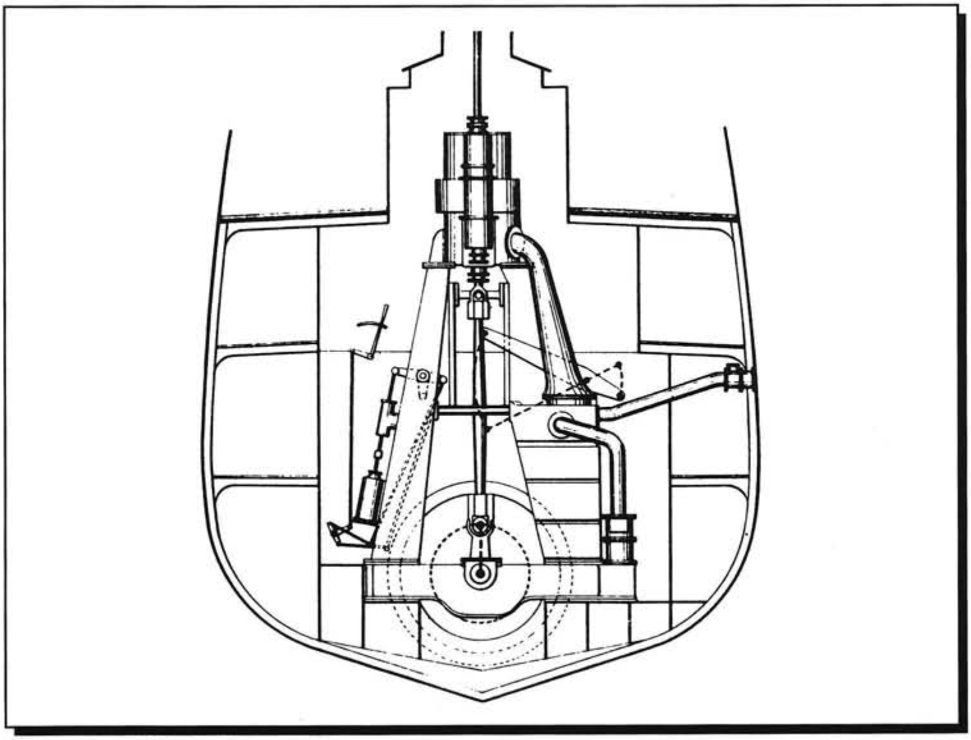


Figure 15: Holt boiler

Steam turbine

The steam turbine is an example of a very ancient idea that was made practicable only by an advance in technology - in this case the widespread introduction of steel and its alloys in the second half of the 19th century. To convert the linear motion of a piston in a cylinder into rotary motion by means of a connecting-rod and crankshaft seemed a roundabout way of doing things. It would be much simpler, surely, to direct a jet of steam on to the vanes of a wheel, like water against a water wheel. This, the principle of the impulse turbine, was suggested as long ago as 1629 by an Italian, Giovanni Branca. The principle of the reaction turbine, that of turning a wheel by jets of steam emerging from its rim like sparks form a Catherine wheel, is even older. It was suggested by Hero of Alexandra in the 2nd century. Yet ever since the beginning of the Industrial Revolution many inventors, including such men as Watt and Trevithick, had experimented - unsuccessfully - with the 'steam wheels' or 'whirling engines'.
For there was a big snag to this deceptively simple idea. Before it could absorb even a useful fraction of the energy of the steam, the wheel would have to revolve with unheard-of velocity. If it failed to do so, the device was woefully inefficient compared with a piston engine. It was Charles Parsons, sixth and youngest son of the Earl of Rosse, who solved this knotty problem, early in his engineering career at Newcastle. He did so by placing a series of vanned wheels on a single shaft and making the steam pass from one to another, the wheels increasing in diameter as the pressure of the steam dropped. In this way, each wheel absorbed part of the steam's energy. Even so, the speed was high. Parson's first turbine patented in 1884, revolved at 18,000 r.p.m. At no earlier date could technology have coped with the demands made by such an invention.
The turbine was subsequently applied to marine propulsion and the Cunarders *Carmania*, *Lusitania* and *Mauritania* were the first large liners to be propelled in this way. But Parson's original idea was to use his invention for generating electricity and he also patented a design for a dynamo capable of being driven at high speed.
Subsequently, rival turbines appeared on the Continent and in America, but Parsons was undoubtedly the pioneer. With the possible exception of Newcomen's steam engine, few inventions have emerged so fully fledged from the brain of one man and few have had social consequences more far-reaching. Nowadays we refer disparagingly to 'the steam age' as if it were a thing of the past, ignoring the fact that an overwhelming proportion of the electricity we use is still generated by steam turbines. These machines are the true descendants of the engine Parsons fathered more than hundred years ago.

Diesel engine

"*Find out more about this!*" wrote the 20-year-old student Rudolf Diesel in his notebook during one of his professor's lectures at the Munich Technical College in 1878. The professor was talking about the poor thermal efficiency of the

steam engine, which can turn only 6-12 per cent of the latent fuel heat into power; he had also explained the theory of the French physicist Nicolas Carnot, the 'father' of thermodynamics, who had stated around 1830 that he could visualise an ideal heat engine that would convert nearly all the latent energy into power. Only an internal combustion engine - where the fuel is burnt inside the cylinder - would be able to approach that ideal system, said the professor. "*That idea kept following me*", recalled Diesel. "*I used every moment I could spare to enlarge my knowledge of thermodynamics.*"
A Cologne engineer, Nikolaus Otto, had already invented an efficient internal combustion engine in 1872, but it ran on town gas and was therefore stationary. However, it was from Otto's engine with its four 'strokes' that two other German engineers, Gottlieb Daimler at Cannstatt and Karl Benz at Mannheim, developed independently of each other the petrol engine for the automobile and the motorcycle, which need an ignition system to make the fuel burn inside the cylinder to move the piston (**Figure 16**).

Diesel worked on somewhat different lines. He aimed at keeping the temperature and pressure in the cylinder fairly constant during combustion so that much more of the heat thus created would turn into power. It took him 14 years before he could write a slim booklet on his engine - which existed only on paper - and take out a patent. Big German engineering firms, including Krupps, enabled him to build his first model in 1893. In the diesel engine, which does not need refined petrol but works with cheaper heavy oil, the heat of the piston-compressed air is increased to such a degree that it ignites the fuel without a special ignition system; the liquid fuel enters the cylinder gradually, so that temperature and pressure are maintained in it throughout the 'power stroke' of the piston. Thus the diesel engine converts 35 percent of the latent fuel energy into power, compared with 28 percent in the most efficient petrol engine. Its disadvantages are that it is heavier and noisier and that heavy-oil exhaust gases are a great nuisance.
Rudolf Diesel lived to see no more than the beginning of the enormous success of his engine, which today powers lorries, busses, taxis, ships and power stations, and - mainly in the form of the diesel-electric system (in which the engine produces current for electric motors) - also railway locomotives. Diesel disappeared without trace from a Channel steamer in 1913, driven to suicide by his desperate financial situation.

Gas turbine

If a basic turbine could be worked by steam, as Hero of Alexandria had suggested in the 2nd century BC and Charles Parsons had demonstrated in 1897, why not then by any other force producing greater power? It was a logical question, and by the 1930s scientists, mainly in Switzerland, had begun to consider the gas turbine as an economic proposition.

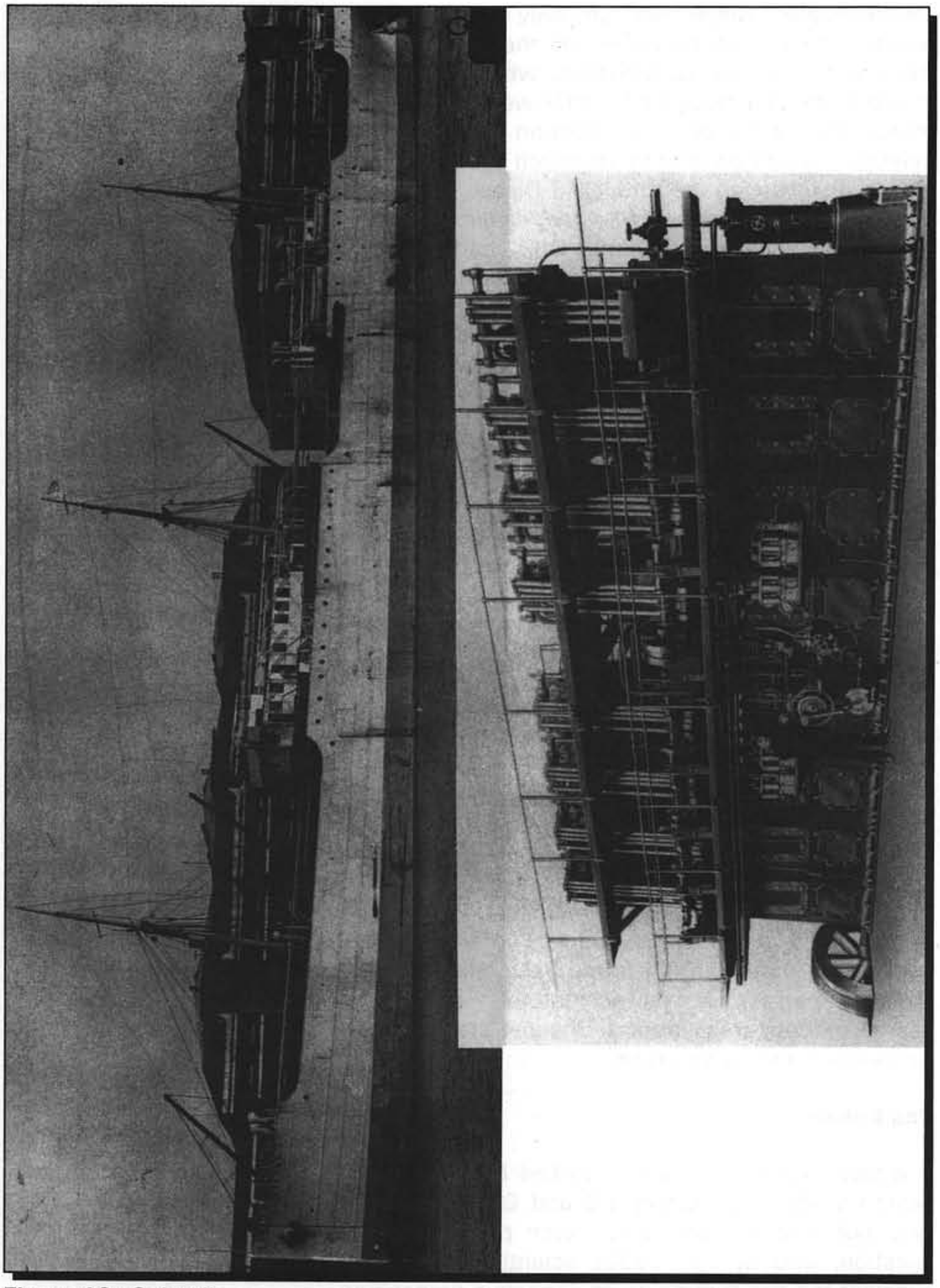


Figure 16: *Selandia*

Basically a gas turbine is a kind of bladed wheel, the blades of which are forced to move by a powerful jet of gas directed on and between them. The blades are fixed to a shaft and thus turn the shaft round with them; the power is taken off the turbine shaft, which belts or gear-wheels can connect to any type of machinery. Air for the gas turbine is drawn in by a compressor and joined in the combustion chamber by injected oil fuel, which is then ignited. The fuel takes fire, expands, and blasts hot gases down into the turbine, thus driving the shaft round and producing power.

At first the advantages of the gas turbine, namely the reasonable initial cost, small size and weight, relatively simple build, and quick starting, were overshadowed by the great disadvantage that special metals were required to withstand the very high temperatures involved, and by the problem of heavy fuel consumption. Apart from Holzwarth's practical gas engine of 1908 it was not until the Swiss firm of Brown Boveri began their work on gas turbines that gas could be looked on as a possible source of power for propulsion. In the mid-1930s, in the oil fields of the United States, some 6,000 kW. gas turbine generating units were being used, and a few years later gas turbines were increasingly in use to provide power for electricity generating at peak periods. However, at first this form of power was not too efficient and it was used sparingly.

After the Second World War gas turbines increased in size and became more efficient. In Britain the first standby gas turbine electricity generator was in operation in Manchester in 1952. In Russia experiments to cut the cost and waste of fuel consumed, have been successful. A 20,000 kW turbine has used cheap piped underground gas, and in 1962 the excess heat generated by a gas turbine unit was first used to heat water.

This form of power is also used in transport. In 1941 the Swiss Federal Railways produced the first gas turbine locomotive, giving up to 2,200 HP. The turbine was found to be more efficient than steam power. The first gas turbine car was made by the British Rover Company in 1950, and later this type of car performed well in motor racing. In 1963 a gas turbine car, entered in the gruelling Le Mans 24-Hour Race, covered 2,553 miles at an average speed of 109.7 m.p.h., with only nine pit stops.

Successfully powered gas turbine fire-engines, and also light portable turbine-driven fire-pumps, have been used for some years now in the United States. At sea a number of navies have favoured gas turbine engines, at least in conjunction with other forms of power, and in aviation, too, gas turbines have formed part of the machinery of jet-propulsion engines, as perfected by Britain's Sir Frank Whittle.

Although in transport the gas turbine engine would seem to offer reliability, lightness, long life and low maintenance, high fuel costs have prohibited its widespread use on railways and motorways. Gas turbine engines are, however, increasingly being used in industry to power machinery.

Navigation

Until the middle of the thirteenth century the overcast skies of autumn, winter and early spring had kept ships in harbour for half the year; without sight of the sun by day or stars by night, pilots quickly lost all sense of direction at sea. But in the last half of that century the trading season of Italian ships in the Mediterranean became progressively extended until, by about 1300, it lasted all the year round. And for the first time Mediterranean ships began trading regularly through the Straits of Gibraltar, past the Atlantic coasts of Spain, Portugal and France to the Low Countries and England.

A series of inventions had begun to transform the art of pilotage into the science of navigation. By about 1190 Italian pilots had begun to use an iron needle floated in a bowl of water and magnetised by a piece of lodestone or magnetite to check on their estimate of the direction of north when skies were overcast. By 1250 this had been developed into the mariners or sea compass, a graduated circular card attached to the needle balanced on a pivot in a glazed box, which thus registered direction all round the horizon by day and, illuminated in a binnacle, by night.

Concurrently, the sand-glass had been developed to give the pilot the means to measure continuously equal intervals of time - usually half an hour or an hour - to enable him to estimate the speed of the ship in miles per hour and hence the linear distance sailed on the course steered over a given time. Methodically written sailing directions giving the magnetic compass direction and distance in miles between places and a geometrically constructed portulan chart, drawn to scale from compass directions and distances, enabled ne pilot to select his course and to plot his progress.

The directional property of magnetite appears to have been identified first by Chinese necromancers about the first century BC; they used a spoon of magnetite in the shape of the Great Dipper to indicate the Pole on a polished copper celestial plate. By about 1090 Chinese pilots, when skies were overcast, were using a south-pointing needle floated in water. The origin of the European compass has not been established.

By 1450 ships had increased in size and better directional control had been achieved by the centre-line rudder and by hoisting sails on three masts. The aftermost lateen sail, while the main propulsion came from the traditional square sails of the north hoisted on the main- and foremasts.

Also by that year the Portuguese were pushing south down the Atlantic coast of Africa in search of Guinea's gold. They needed an aid to check their charted reckoning of course and distance sailed. Astronomers taught them to measure and record on a quadrant the altitude of the Pole Star at Lisbon and to covert the angular differences into miles sailed.

They thus learned to check their estimated position by scientific measurements independent of the effect of ocean currents and human errors.

Sextant

In order to find out how far north or south you are, it is necessary to have an instrument that can determine the latitude by measuring the angle between the horizon and sun at noon, or some fixed star. At first the mariner's astrolabe was used to 'shoot the sun', but this was too unwieldy for the heaving deck of a ship. It was replaced by the cross-staff, which remained in use for centuries until the introduction of the sextant.
The cross-staff was a piece of wood or bone on which was inscribed a scale along which a cross-piece could be moved to measure the altitude of the sun. A great improvement was made when an Elizabethan explorer and navigator, John Davis of Dartmouth introduced the back-staff from the Arabs in the Indian Ocean because, by using an eye-slit in the horizon vane, the observer could turn his back on the sun and avoid being dazzled.

In 1731 John Hadley (1682-1744) invented a reflecting quadrant which superseded the cross-staff and was soon developed into the sextant, that is to say an arc measuring the sixth of a circle. Hadley was the first of the betterknown Halley, with whom he developed a reflecting telescope when he became a Fellow of the Royal Society. He then made an instrument for measuring angles at sea with which the observer looked at the horizon and at the sun at the same time by means of a mirror, thus bringing two objects together by reflection (an idea originally suggested by Isaac Newton). The angle between them could be measured on a graduated scale inscribed round the edge of the quadrant, on which there was a sliding vernier scale with minute subdivisions. When a small telescope or shade tube was fitted, observation became easier and sights could be taken independently of the roll of the ship.
The quadrant was tested on board of a yacht by order of the Admiralty in 1732 and its readings were so accurate that it was officially adopted in the Navy. In 1757 Captain John Campbell extended the arc of this quadrant to measure angles up to 120 degrees instead of 90 degrees and the instrument became known as a sextant.
It consist of a triangular frame, one side of which is an arc on which there is a scale of degrees. An index pointer pivots across the frame and the arc, and a system of reflecting mirrors brings together the two objects whose angle is to be observed.

Marine chronometer

Ever since navigation began, the difficulty of ascertaining a ship's position east or west had proved insuperable. It was certainly realised that what was needed was a clock that would keep such good time that a comparison between local time and the time at the Prime Meridian (Greenwich was not internationally accepted as such until 1884) would give the correct position east or west. But no one could make a timepiece able to withstand the motions of a ship or the changes of temperature on a long voyage. Even an error of two minutes would put you 30 miles of course.

The system of using a ship's log to measure distance travelled did not allow for drift or current, and enormous errors resulted. A complicated alternative to the log, called the 'lunar method', depended on elaborate calculations. It was used by Captain Cook on his first voyage round the world.

Every government offered a prize for a solution to the problem. The French Academy was founded for the purpose, and the Royal Observatory was established at Greenwich in 1675 'to find out the so-much desired longitude of places'. In 1714, after the flagship of Sir Cloudesley Shovell had been wrecked on the Scillies (when he imagined that he was sailing up the Channel), the British Admiralty set up a Board of Longitude to offer a prize of £ 20,000 for a clock with an error of less than two minutes on a voyage to the West Indies and back.

John Harrison (1693-1776), a self-educated Yorkshire carpenter, entered his first clock or chronometer for the prize in 1735. He spent the next 30 years improving it and reducing its size from the 72 lb. of his first model to the handsome watch which was his fourth model in 1761. His son took this model on a test voyage under the supervision of an astronomer. When the ship was approaching Madeira, the longitude shown by the chronometer and that estimated by the pilot differed by more than 2°. The pilot begged the captain to alter course to reach the island, but Harrison asked him to wait for a few hours. The captain did so and the island came in sight as Harrison predicted. After a voyage lasting 81 days, the ship reached Jamaica where the chronometer was found to be only five seconds slow. It was a duplicate of this model, made by Larcum Kendall, which Cook took on his second voyage in 1772-75, and which was only 7 minutes 45 seconds slow after three years at sea in temperatures ranging from tropical to polar.

The movement in Harrison's chronometer was controlled by two balances connected by springs, which were adapted to changes of temperature by a 'compensation curb' of brass and steel rods. The mainspring was partially rewound every seven seconds, with a 'maintaining power' to prevent the clock going slow during the process.

This was the greatest advance in the art of navigation ever made, but the Admiralty refused to pay the full prize money. "*By God, Harrison, I'll see you righted*", exclaimed George III when the 80-year-old inventor appealed to him. Even then, £ 1,000 was deducted for the cost of constructing a watch Their Lordships had ordered.

Radar

Radar was made to happen by Robert Watson-Watt; others had made it possible. In the 1880s Heinrich Hertz, experimenting with Clerk Maxwell's theories of electromagnetic waves, found that the 'sparks' which he generated were reflected from the pillars of his laboratory. In 1900, Nikola Tesla suggested that moving ships could be located by radio reflections. In 1924, Edward V. Appleton

and his colleague, Miles A.F. Barnett, employed signals transmitted from the ground and reflected back from an ionised layer to establish the existence and height of the 'mirror in the sky', the Appleton layer of short-wave telecommunications.
In 1952, Gregory Breit and Merle A. Tuve contributed the pulse-signal. In 1934, the British Air Ministry committee, under Sir Henry Tizard, referred to the Government Radio Research Station, of which Watson-Watt was superintendent, the perennial 'death ray' which was supposed to paralyse an aircraft in flight. Watson-Watt and his colleague A.F. Wilkins did the calculations of energy requirements which brusquely disposed of the death ray, but Watson-Watt on half a sheet of paper spelled out 'radiolocation', showing that detection of moving aircraft was a practical proposition. A month later, he gave an actual, and successful, demonstration. The result was a chain of radiolocation stations, which protected the eastern approaches of Britain and proved their effectiveness in the first German raid of the Second World War, when an aircraft was detected, tracked and destroyed in the Firth of Forth.
Airborne systems became possible with the development by J.T. Randall, J. Sayers and H.A.H. Boot of the cavity magnetron, a device so compact that Tizard could take it to the United States in his pocket, yet capable of generating pulses of energy equivalent to a large broadcasting transmitter. With such refinements, pilots were able to detect their adversaries in the air and bombers could turn a radio-searchlight of invisible rays on to a ground target and see the details on a cathode ray screen. Bombs and shells, fitted with radar proximity fuses, could respond to the echoes of their own signals and near misses became direct hits.

Refrigeration

Refrigeration as known today was invented by Jacob Perkins, an American who spent most of his long and active life in England. In his British Patent Specification of 1834 he described the vapour compression cycle, in which cooling was produced by the evaporation of volatile fluids, "*yet at the same time constantly condensing such volatile fluids and bringing them again and again into operation without waste.*" The story goes that one summer's evening a working model succeeded in making a small amount of ice, which the exited mechanics wrapped in a blanket and carried by cab across London to Perkins' lodgings.
Perkins dit not develop his invention, however, which he made late in life. Possibly independently James Harrison, a Scottish printer who had emigrated to Australia in 1837, was working on similar lines. He is said to have noticed the cooling effect of ether while using it to wash type. Machines to his design were made by Daniel Siebe and shown at the International Exhibition of 1862. These were the first refrigerators to be marketed.
Harrison had been inspired by the need to bring Australian meat to Britain, but his attempt to ship meat in 1873 was a disastrous failure. The need remained pressing, however. In 1867 The Times contrasted the superabundance of food in Australia with the starvation at home, and called it a 'cruel reproach to

modern science'. The reproach was removed in 1880 when the Strathleven arrived in London with a small cargo of sound meat. It had not in fact been refrigerated by Harrison's method, but the first link in the 'cold chain', which now extends round the world had been forged.
By the turn of the century refrigeration was being freely applied for preserving food and also for a host of industrial processes. Soon the American Willis H. Carrier was showing how it could be applied to give comfortable conditions in buildings by air-conditioning.

Hydrofoil

Like the hovercraft, the hydrofoil is a 'skimmer' or boundary vehicle, moving in the region where the air meets the sea. While ordinary ships have to overcome water and air resistance - the 'drag' - the hydrofoil uses the air to lift itself as much as possible out of the water by means of wings or foils to reduce drag to a minimum; but it never leaves the water completely to fly like an aeroplane.
The first inventor to have worked on the idea was a French priest by the name of Ramus in the middle of the last century; he took his cue form the kite. Another Frenchman, the Russian-born Count de Lambert, understood that the petrol engine, then newly invented, would provide the necessary power for his 'hydroplane', as he called it. He tried his prototype out on the Seine in the 1890s, but it refused to lift its nose out of the water, (**Figure 17**).

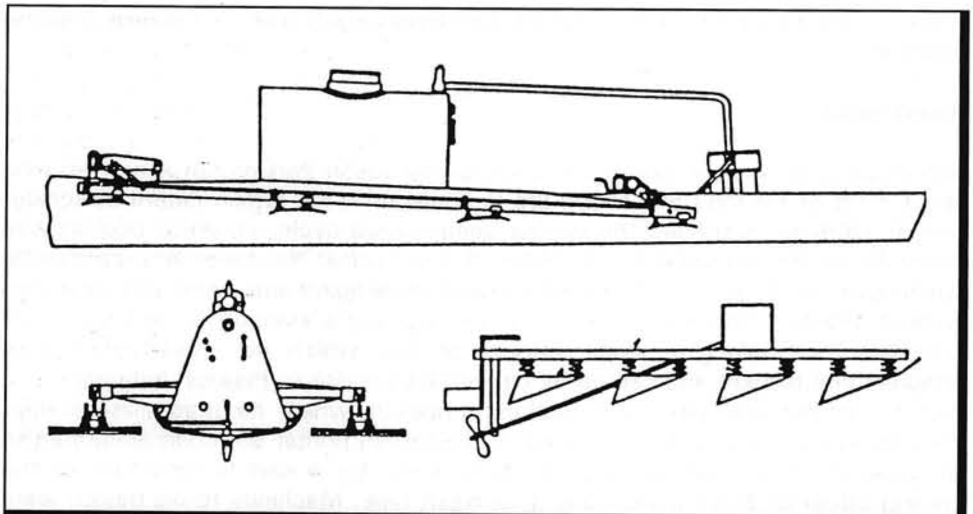


Figure 17: C. de Lambert, 1891

Now it was an Italian who took up the idea: Enrico Forlanini, an airship designer. He built a small hydrofoil boat in 1905, expounding the scientific and technical principles of the craft in his patent specification. Forlanini improved his sub-

sequent models, demonstrating his last one in 1911 to a distinguished American visitor, Alexander Graham Bell, on Lake Maggiore. Bell proceeded to build a craft of his own design, based on Forlanini's patent, in Halifax, Nova Scotia; it established a water-speed record, at 71 m.p.h., in 1918. Further improvements were made by German inventors in the 1920s and 1930s, and later by a British organ-builder, Christopher Hook, during and after the Second World War. Commercial hydrofoil building, however, began in the 1950s in Italy with the 'Supramar' boats; they are also produced under licence in many other countries, while the USA and the Soviet Union have created their own designs for big military and passenger boats. Today, hydrofoil craft are maintaining regular passenger services all over the world, from the Thames to the Black Sea.
Nearly all types have a rather clumsy look - like giant insects with bow legs; their lack of elegance is due to the V-form arrangement of the foils, which means that the struts holding them stick out right and left from the hull. But the craft has proved most useful for fast commuter services, for fishery patrol, firefighting, harbour control, water-police purposes, and for air/sea rescue. Men working on oil-drilling platforms offshore can be taken to and from their artificial islands at top speed. The hydrofoil is faster than anything afloat, with the exception of speedboats; these, by the way, can be converted into hydrofoils at low cost, by fitting hydrofoil fins to the bows and the outboard engines.

Hovercraft

In 1876 John Ward proposed a machine provided with two supporting and one steering wheel (**Figure 18**). This proposal was the beginning of the hovercraft.
Two tins, a vacuum cleaner and an English engineer of rare detachment and persistence were the keys to the elements of the hovercraft. It had been known for years that a special kind of 'lift' helps to support aircraft flying very close to the ground. A helicopter just clear of the ground may need no more than a quarter the power it needs to hover at height. Lindbergh made use of this 'ground effect' to save fuel on his famous transatlantic flight in the 1920s. Various people in several countries tinkered with the 'ground effect'. The Americans spent US$ 3,000,000 in a fruitless attempt to apply the principle to naval craft.
In 1950, after a tough war in the demanding field of radio engineering, Christopher Cockrell turned boatbuilder on the Norfolk Broads and found that two factors greatly reduced his boat's performance - skin resistance and wave resistance. 'If I could make the skin of my craft a skin of air, i.e. introduce a film of air between hull and water, skin friction would be negligible'.
He found that by blowing air through open-ended tins of different sizes downwards on to his kitchen scales, he achieved vastly different readings. The same mass of air through the narrow tin exerted up to three times as much thrust - which was contrary to the classical laws of physics. He was on to something.
A working model of Cockerell's hovercraft flew over the most illustrious carpets in Whitehall in 1955 - and was taken out of the inventor's hands and put on the

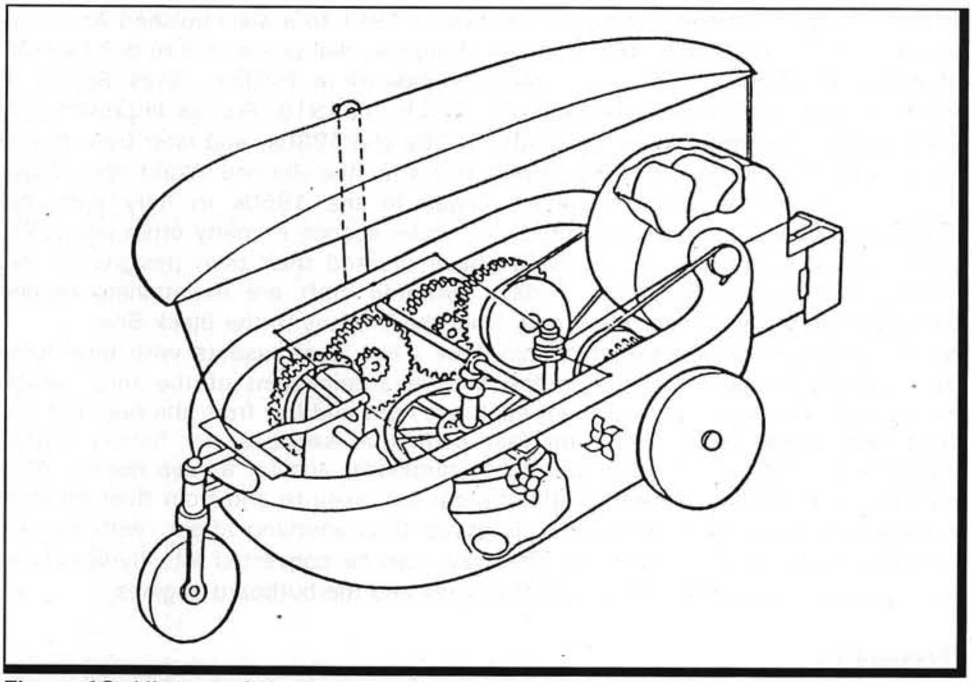


Figure 18: History of the hovercraft

Secret List where no one wanted it. It was finally prized loose through the enterprise of a farsighted civil servant, R.A. Shaw, who authorised a small feasibility contract. The report was favourable and was the turning-point in obtaining the money necessary to transform a bright idea into a viable production item. On 11 June 1959, a full-scale overwater craft, *SRN-1*, was shown off to the Press - and received rave notices across the world. On the fiftieth anniversary of Bleriot's first Channel crossing in 1909, *SRN-1* repeated the performance in the opposite direction.
The key to practicality proved to be the manipulation of the air-jets beneath the craft and the refinement of the British-patented 'skirt' which keeps effective contact with the surface, while avoiding actual hard contact. Cockerell's concept has produced not just a flying-boat, but a family of new transporters.

4.3 Basic innovations 1740-1960

G. Mensch has analysed the historical patterns of invention and innovation, which are published in *"Das technologische Patt, Innovationen überwinden die Depression"*. C. Marchetti has summarised this fundamental work into three tables and one graph, which are shown in **Table I** to **Table III** and **Figure 19**.

Basic innovations, which are defined as those innovations that give rise to a brand new industry, are divided into ten year periods. The average frequency over the period 1740-1960 is five basic innovations per decade, while the trend increases over time from 2 per ten years to 10 in more recent times (**Figure 19**). These data are used by Marchetti to demonstrate the correctness of the Kondratiev waves, which are discussed in another chapter.

	Invention	Innovation
Power generator	1820	1849
Electromedical stimulator	1831	1846
Deep sea cable	1847	1866
Electicity production	1708	1800
Insulated conductors	1744	1820
Arc lights	1810	1844
Pedal bicycle	1818	1839
Rolled rails	1773	1835
Rolled wires	1773	1820
Puddling furnace	1783	1824
Blast furnace with Coke	1713	1796
Crucible streel	1740	1811
Locomotives	1769	1824
Telegraph	1793	1833
Lead chamber process	1740	1819
Pharmaceutical industries	1771	1827
Quinine industries	1790	1820
Hard rubber	1832	1852
Portland cement	1756	1824
Potassium chloride	1777	1831
Photography	1727	1838

How invention and innovation dates are chosen: The case of locomotives.	
1769	Watt: Low pressure machine
1770	Cugnot: Steam gun vehicle
1790	Read: Steam road vehicle
1800	Wat's patent on steam engines expires
1801	Trevithick starts work on locomotives
1804	Evens: Road Locomotive
1811	Blenkinskop: First toothed gear locomotive
1813	Hadley: Locomotive on rails
1814	Stephenson starts work
1824	Stephenson build first locomotive plant
1825	Stephenson opens Stockton-Darlington line

Table I: The 1802 cycle

	Invention	Innovation
Thomas steel	1855	1878
Safety matches	1805	1866
Aniline dyes	1771	1860
Cooking fat	1811	1882
Indigo synthesis	1880	1897
Sodium carbonate	1791	1861
Aluminium	1827	1887
Refrigeration	1873	1895
Rayon	1857	1890
Gas heating	1780	1875
Oxyacetylene welding	1862	1892
Dynamite	1844	1867
Chemical fertiliser	1840	1885
Preservatives	1839	1873
Electrolysis	1789	1887
Antitoxin	1877	1894
Chloroform	1831	1884
Lodoform (antiseptic)	1822	1880
Veronal (barbiturate)	1862	1882
Aspirin	1853	1898
Phenazone (synthetic painkiller)	1828	1883
Baking powder	1764	1856
Plaster cast	1750	1852
Mass production of sulphuric acid	1819	1875
Synthetic alkaloid (cocaine)	1844	1885
Synthetic alkaloid (chinoline)	1834	1880
High-grade steel	1771	1856
Electrodynamic measurement	1745	1846
Lead battery	1780	1859
Double armature dynamo	1820	1867
Commutator	1833	1869
Cylinder armatured motor	1785	1872
Arc lamp	1802	1873
Incandescent light bulb	1800	1879
Electiric locomotive	1841	1879
Electric heating	1859	1882
Cable construction	1820	1882
Telephone	1854	1881
Steam turbine	1842	1884
water turbine	1824	1880
Transformer	1831	1885
Resistance welding	1841	1886
Arc welding	1849	1898
Induction smelting	1860	1891
Meters	1844	1888
Electric railroad	1879	1895
Long-distance telephoning	1893	1910
High tension insulation	1879	1910
Gasoline motor	1860	1886

Table II: The 1857 cycle

	Invention	Innovation
Nylon, perlon	1827	1938
penicillin	1922	1941
Polyethylene	1933	1953
Power steering	1900	1930
Radar	1887	1934
Radio	1887	1922
Rockets	1903	1935
Silicones	1904	1946
Streptomycin	1921	1944
Sulzer loom	1928	1945
Sythetic detergents	1886	1928
Gyrocompass	1827	1909
Synthetic light polariser	1857	1932
Television	1907	1936
'Terylene' polyester fiber	1941	1955
No-knock gasoline	1912	1935
titanium	1885	1937
Transistor	1940	1950
Tungsten carbide	1900	1926
Xerography	1934	1950
Zipper	1891	1923
Automatic drive	1904	1939
Hydraulic clitch	1904	1937
Rollpoint pen	1888	1938
Catalytic cracking of petroleum	1915	1935
Watertight cellophane	1900	1926
Cinerama	1937	1953
continuous steelcasting	1927	1948
cntinuous hot strip rolling	1892	1923
cotton picker (Campbell)	1920	1942
Cotton picker (Rust)	1924	1941
Wrinkle-free fabrics	1906	1932
Diesel locomotive	1895	1934
Fluorescent lighting	1852	1934
Helicopter	1904	1936
Insulin	1889	1922
Jet engine	1928	1941
Kodachrome	1910	1935
Magnetic tape recording	1898	1937
Plexiglas	1877	1935
Neoprene	1906	1932

Table III: The 1921 cycle

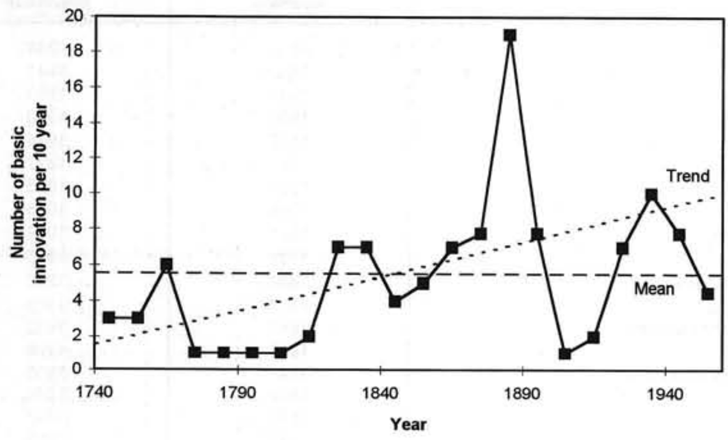


Figure 19: Frequency of basic innovations

4.4 Basic innovations in shipping

World shipping is and has been over the past centuries a virtual laboratory in which new technologies, new design concepts, new trades, new construction methods, and so on have been tried and tested continuously. The distance between an innovative idea and trying it in reality always has been very small; shipping facilitates the trial and error (commercial) process of innovative development. This unlike for example the aeroplane industry, where extensive prototyping and testing during many years, preceed the certification to be air-borne.

The low threshold between idea and implementation is one of the reasons why there is such a phenomenal stream of innovations. The number of basic innovations, which create a whole new shipping market, is of course smaller than the hundreds of improvement innovations on and around ships. Ships can not be seen in isolation, but are usually part of a logistical chain. The basic innovation of the container ship would not have functioned without parallel innovative developments in the terminal sector. It is therefore important to look at innovations in shipping in a holistic way, and not in isolation, focussed on the ship as an asset only.

The basic innovations in shipping can be classed in various ways. The simplest one is based on the distinction in the use of the ships, such as merchant vessels, service vessels, industrial vessels, and naval vessels. Merchant vessels comprise all ship types that are performing a transport service in which cargo or passengers are actually transported between various ports. Service vessels comprise all ship types that provide services, for example to assist ships to berth. On industrial vessels the main activity is not transport, but an industrial activity; the ship is a floating production unit. Another important category is the naval vessels that have a defense purpose; a lot of innovation goes into this category of ships. **Table IV** shows a non-exhaustive overview of the many ship types in the four basic categories.

Commercial vessels	Industrial vessels	Service vessels	Naval vessels
- General cargo ships - Container ships - Tankers - LPG carriers - Bulk/OBO carriers - Roll-on/roll-of ships - Ferries - Passenger ships - Heavy lift ships - Chemical tankers - Tug barge - Barge carriers	- Suction dredges - Pipe-laying vessels - Drilling vessels - Semi-submersibles - Incinerator vessels - Fish processing - Research vessels - Ocean mining - Seismic exploration	- Tug boats - Offshore supply - crew boats - crane support ships - Diving support ships - Fire boats - Pilot boats	- Frigates - Minesweepers - Submarines - Aircraft carrier

Table IV: Innovation in shipping

The description of the basic innovations in shipping would require the space of a whole book by itself. Therefore, in the context of this book on design, the reader is referred to a number of existing publications that cover the subject in much detail. Apart from the references in the Chapter Notes, the reader is suggested to consult the excellent series by Conways on the development of world shipping since 1600, see Chapter Notes. For more recent developments, another excellent source is the annual report by the Japan Shipbuilding Association, see Chapter Notes.

CHAPTER 5: TECHNOLOGICAL INNOVATION AND ECONOMIC GROWTH

Technological innovation is and has been in the past the driving force behind economic growth. It is par excellence the domain of the engineer, and probably his/her main mission and contribution to the economic development of a country.
In two chapters, the role of technological innovation will be highlighted, starting with an overview of the theory on innovation. Next, the focus will shift from general economic analysis towards the level of the firm.

5.1 Models of the innovation process

5.1.1 General innovation models

Blackwell and Eilon, in their book *"The Global Challenge of Innovation"*, present two models of the systematic innovation in a competitive environment, the *linear model* and the *market model*.
The *linear model* (**Figure 1**) shows the set of sequential steps in this concept, starting from pure research and culminating in the production of goods and services to meet market demand. The participants in this process are the universities and industry with the former concentrating their effort on pure and applied research and the latter converting this research base into wealth-generating products. The authors reject this model as simplistic and misleading and propose the market model instead, as shown in **Figure 2**.

The higher the technology, the more difficult it is to get the technical champion of a product to address the question of the market for it. Its newness, Blackwell and Eilon, argue, is used to discredit any comparisons with previous products and even to imply that its outstanding technical merits will result in it being bought at any cost. Concorde, the supersonic civil airliner, was launched in almost total disregard of the economics of its purchase and subsequent operation.

The difficulty of getting product pricing considered at the earliest possible stage of the innovation cycle, is exceeded by the unwillingness to address the subject of sales volume - and yet it is only through sales volume that the recovery of the launch investment can be made and the all-important selling price constructed.
In the *market model*, the market need (and not technological research) as the genesis of innovation, is seen as the driving force.

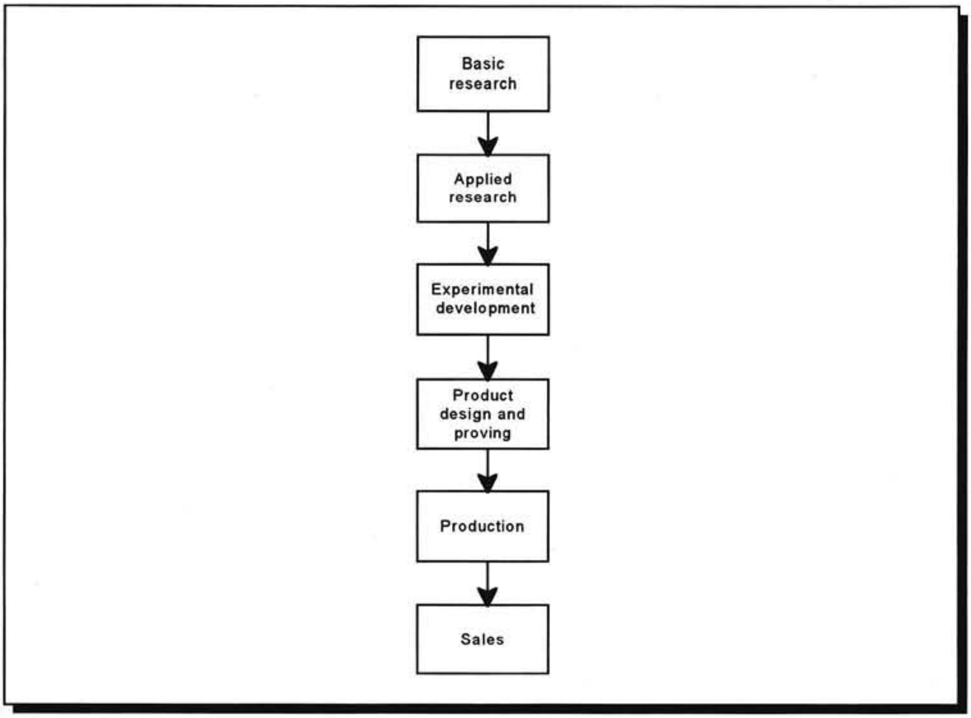


Figure 1: The linear model

The authors add that both models are an oversimplified version of the disorderly reality of a creative activity and continue to state that the process of product design and innovation is even more chaotic: "*a veritable spaghetti junction of mutually overlapping and conflicting streams of ideas out of which a hopefully optimum design will emerge*". They illustrate this by **Figure 3**. The detailed product innovation process will be discussed later.

Rothwell and Zegveld describe in their book *"Reindustrialisation and Technology"* the linear and market models of Blackwell and Eilon in slightly different terms, as *technology push* and *need (market)-pull* (**Figure 4**).
They state that during the past decade, both the pure technology-push and need-pull models of innovation have increasingly been regarded as extreme and untypical examples of a more general process of coupling between science, technology and the marketplace.
Technology-push means not necessarily that more research and development will result in more innovation, while overemphasis on market-pull can result in a regime of technological incrementalism and lack of radical innovation. Moreover, the relative importance of technology-push and need-pull might vary considerably during the different phases of the industry cycle. Rothwell and Zegveld therefore propose their own *interactive model* of industrial innovation (**Figure 5**).

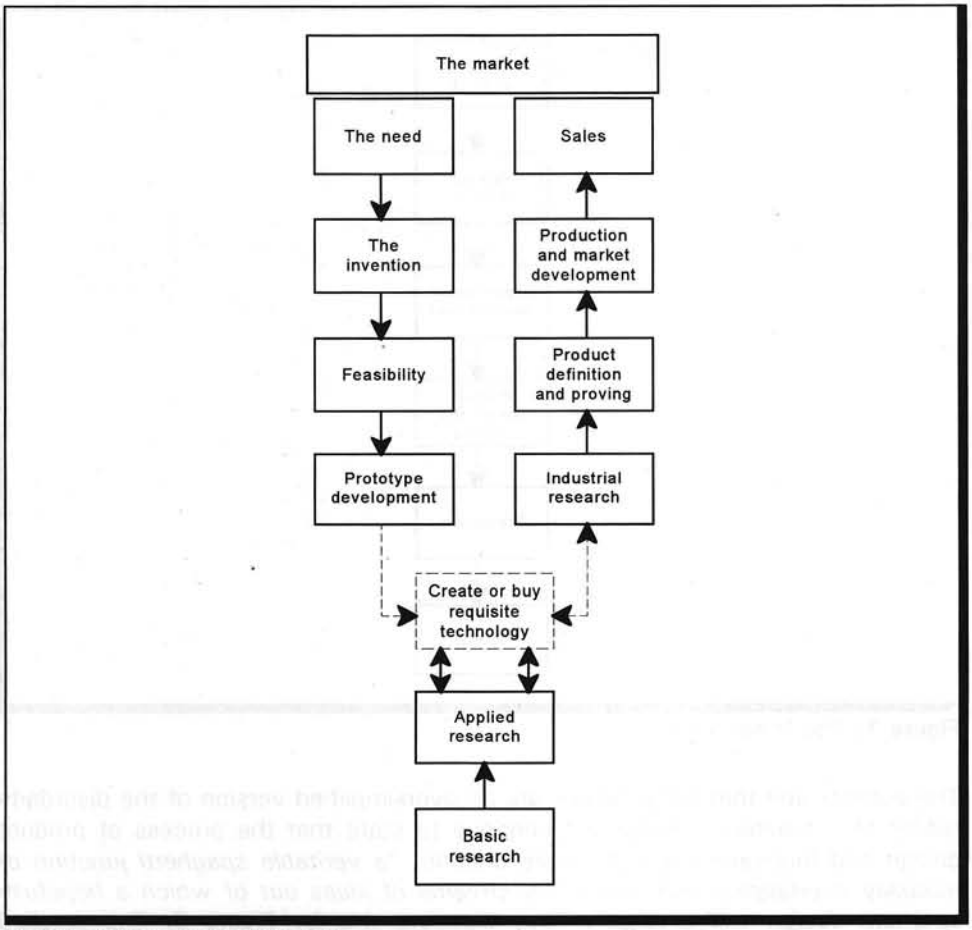


Figure 2: The market model

According to this model, innovation is regarded as a logically sequential, though not necessarily continuous process, that can be subdivided into a series of functionally separate but interacting and interdependent stages. The overall pattern of the innovation process can be thought of as a complex network of communication paths, both intra-organisational and extra-organisational, linking together the various in-house functions and linking the firm to the broader scientific and technological community and the marketplace. In other words, the process of innovation represents the confluence of technological capabilities and market needs within the framework of the innovating firm.

Rothwell and Zegveld discuss in their book various other models of innovation, which are partly variations on the previous models. The model from Schmookler is based on *demand-led invention* (**Figure 6**). The model from Hessen is based on

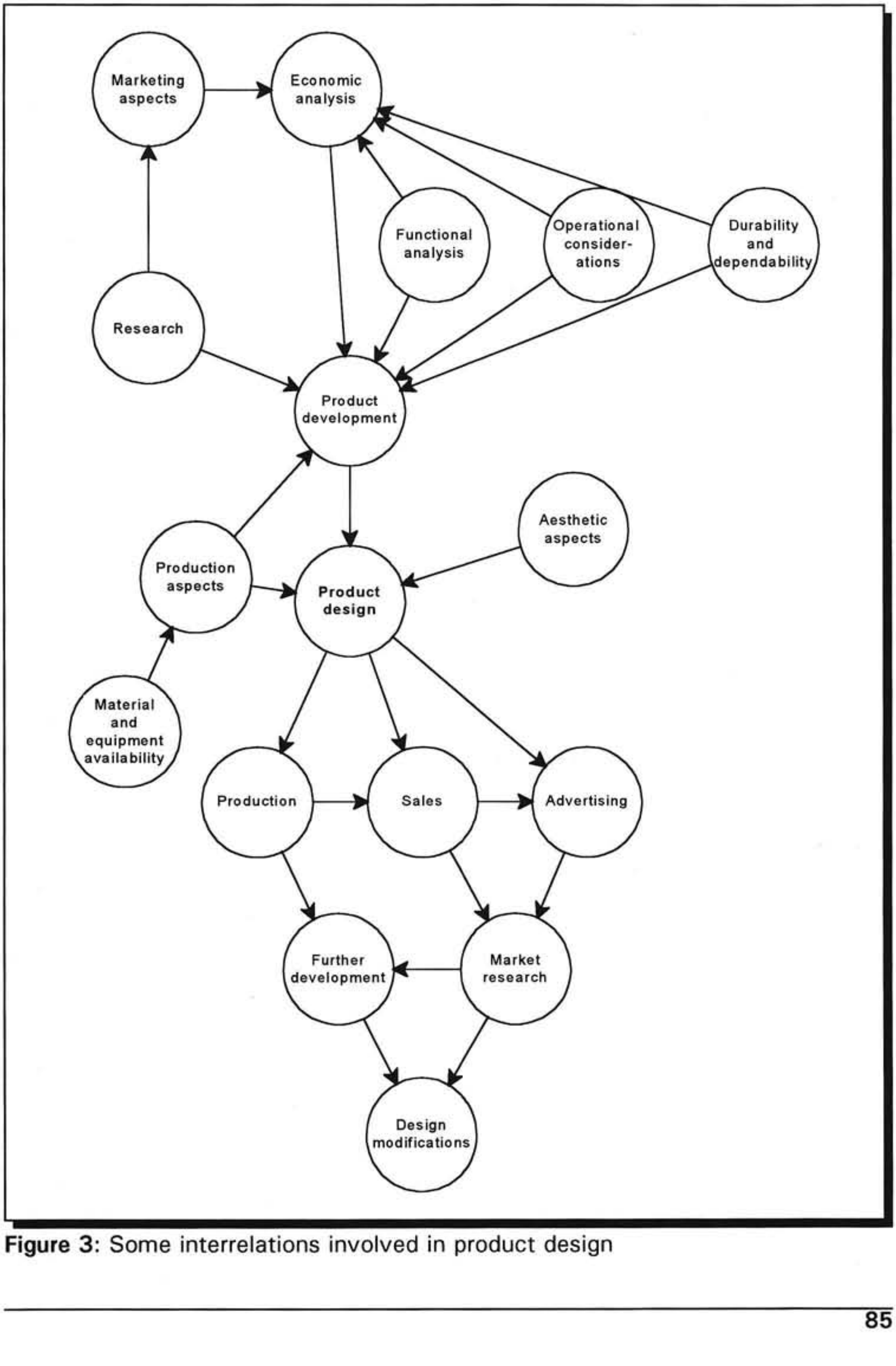


Figure 3: Some interrelations involved in product design

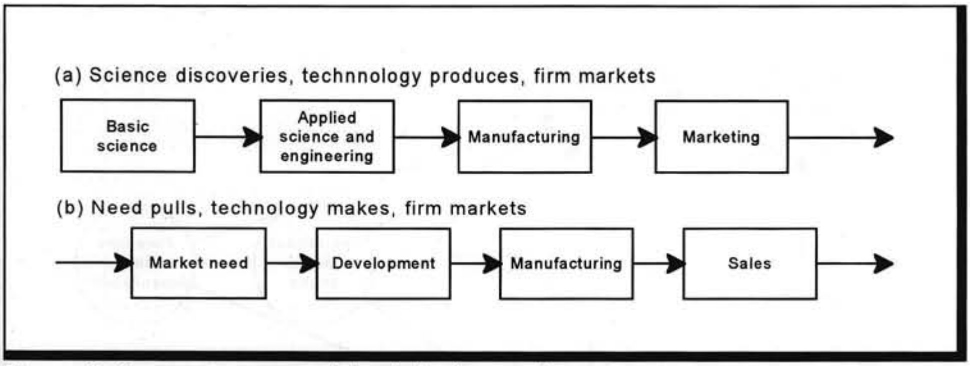


Figure 4: Two extreme models of the innovation process

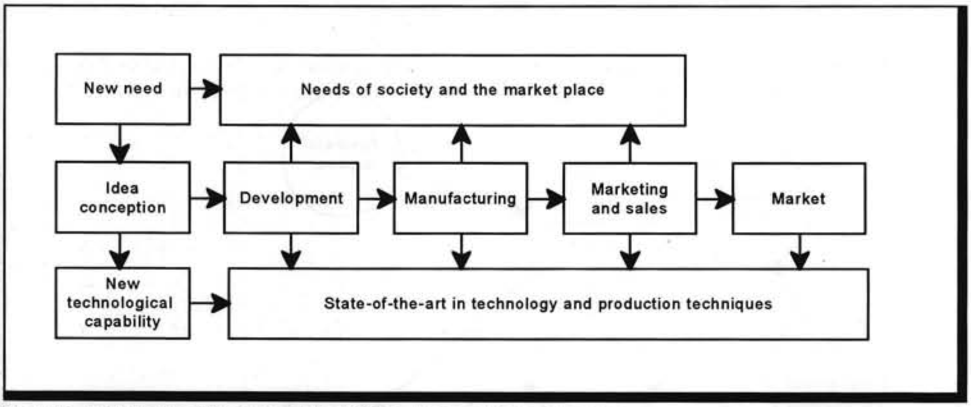


Figure 5: Interactive model of the innovation process

technology and demand-led innovation (**Figure 7**). These two models resemble in some sort, the linear and market models discussed before.

However, the models from Schumpeter add a new dimension to the innovation model. Schumpeter's first model (**Figure 8**) stressed the importance of *exogenous science and invention* that, via the medium of entrepreneurial activity, led to the growth of new industrial branches and new areas of demand.

Schumpeter's second model (**Figure 9**) emphasized the role of *endogenous science and technology*, which again led to new patterns of production and new market structures.

Researchers have tried to validate the innovation models on the basis of actual innovation case-studies from the past. From this empirical work it became clear that the relationships between science, technology and the marketplace are complex, interactive and multidirectional. The dominant driving force varies over

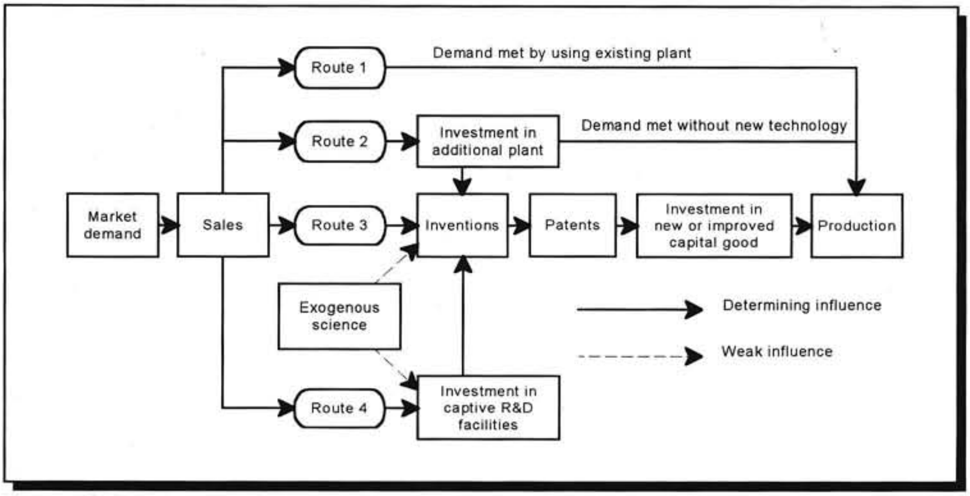


Figure 6: Diagram of Schmookler's model of demand-led invention

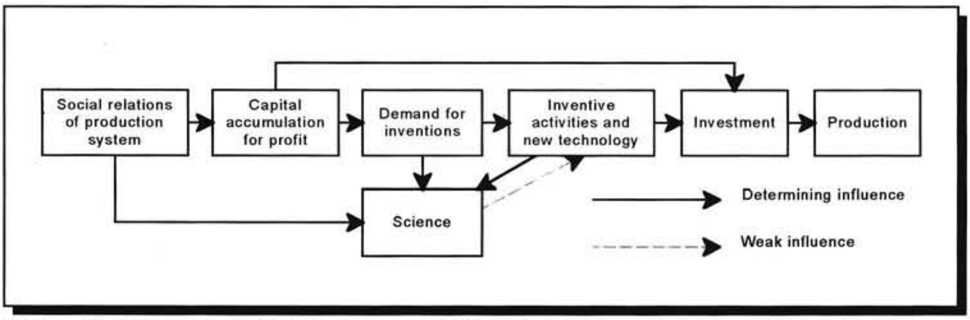


Figure 7: Diagram of Hessen's model of technology and demand-led science

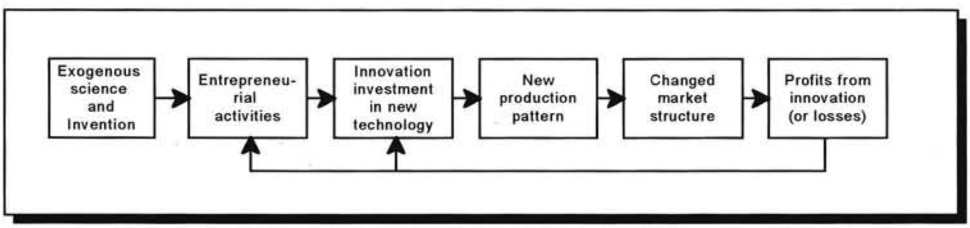


Figure 8: Diagram of Schumpeter's Model of entrepreneurial innovation (I)

time and between one branch of industry and the next. Innovation is a process of coupling. It should be a primary aim of policy to forge the necessary links, to adjust the balance of resources and to match the pattern of requirements for each technology or industry at its particular stage of development.

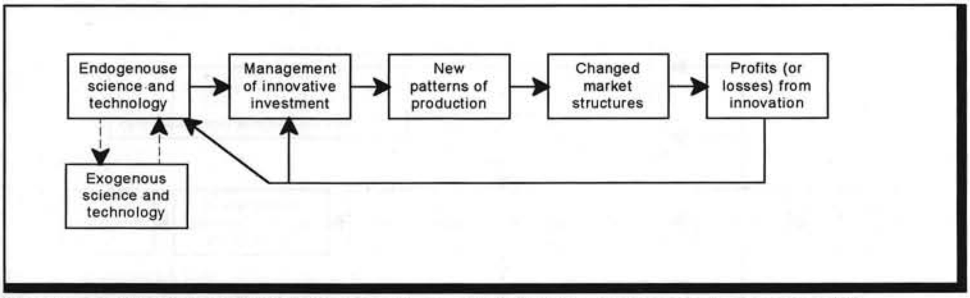


Figure 9: Diagram of Schumpeter's model of firm managed innovation(II)

5.1.2 Network model

In the book *"Industrial Technological Development; a Network Approach"* H. Håkansson (edit.) yet another model of innovation is presented, which is an extension of the second model of Schumpeter. It is the model of technological innovation through ***network interaction***. Instead of creating all the research capabilities in-house, the network model demonstrates how various (smaller) companies act virtually as one in a network fashion (**Figure 10**). This model consists of four groups of variables:

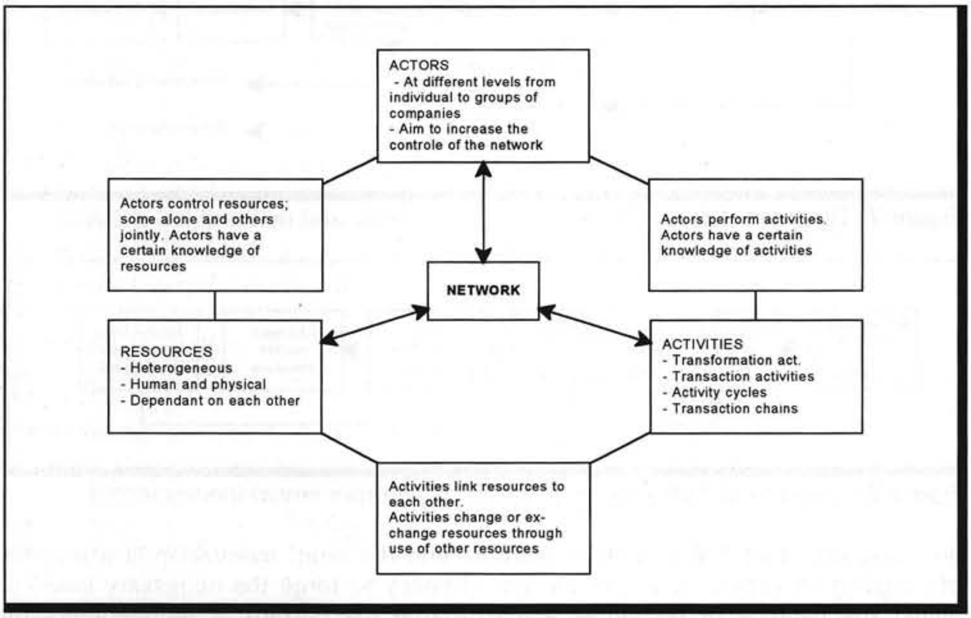


Figure 10: Network model

- The interaction process;
- The participants in the interaction process;
- The environment within which interaction takes place;
- The atmosphere affecting and affected by the interaction.

The network interaction model is a theoretical description of the development of relationships in industrial markets. These relationships are made by the company in order to serve certain functions, such as:

- To increase productivity or technical efficiency;
- To serve as information channels;
- To increase control and cohesion within the network, through technical and other bonds.

An example from the Swedish specialty steel manufacturing sector may illustrate the network model more clearly. **Figure 11** shows the Process Technology Network seen from the perspective of the Swedish steel industry.

In order to stay ahead of the competition, the industry wished to innovate certain steel making processes. The network cooperation in partuicular of the two main players in Sweden, ASEA and Stora, resulted in a new metalurgical process. The network model of innovation is a predecessor of Porter's Diamond model, which will be discussed later on.

5.2 Innovation and economic growth

The network model is more of an organisational model of innovation than a basic conceptual model of innovation. It underlines much of the work later on presented by M. Porter in his diamond-theory of competitive advantage.
In the nineteenth century, innovation was driven by the individual inventor and his personal gain from the monopoly that would protect his brainchild, through patents and royalties. Companies at that time were established solely for the purpose of developing, making and selling specific inventions and the failure rate was high. Edison, who created an empire on the basis of his inventions, is a good example of the inventor-entrepreneur.
Organising and managing the innovation was an issue of far less importance in such a world. Gradually companies started to build up their own in-house innovative capabilities, beginning with the improving and commercialising of the inventions of others. By the 1920s, the separate existence of the inventor and manufacturer had become blurred and many inventions were anonymous. With the development of organisations dedicated to research and the steady rise of public and private investment in R&D, however, issues of structure and management became more important.

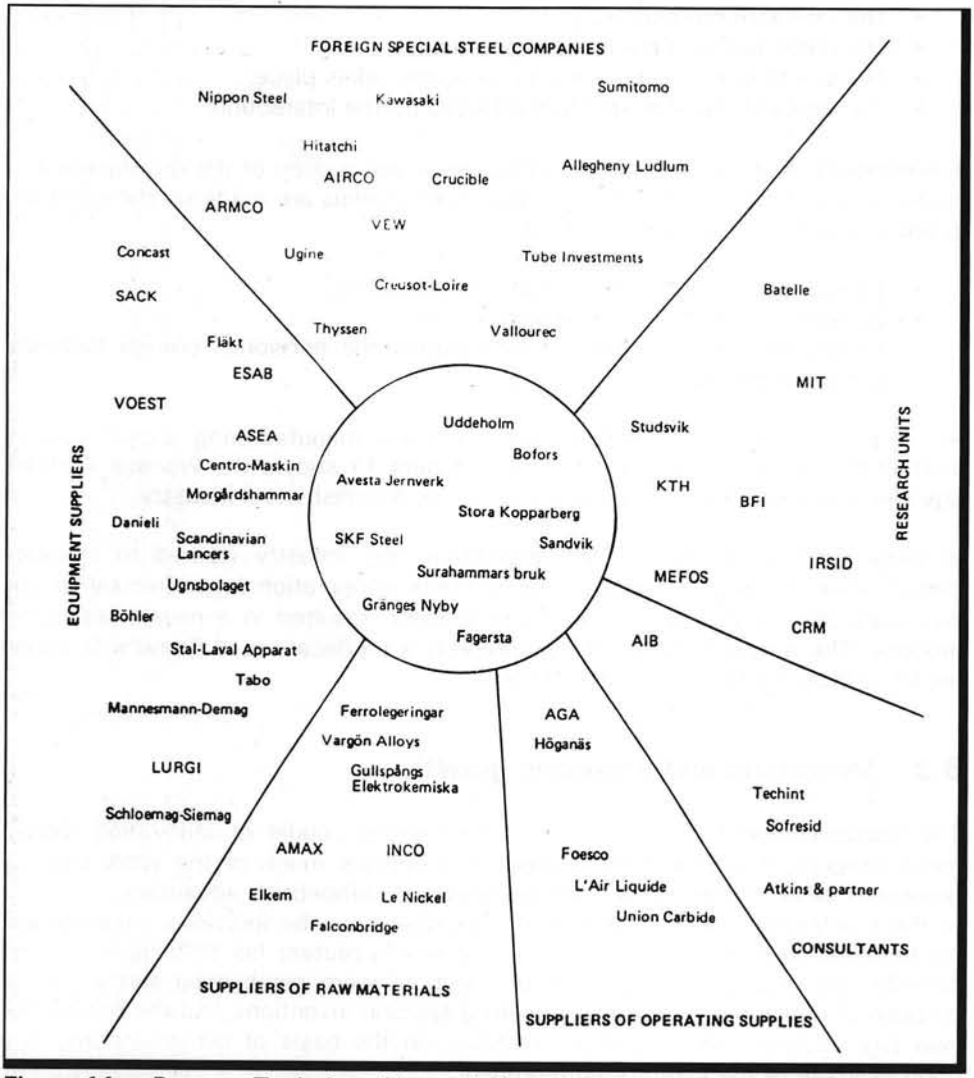


Figure 11: Process Techology Network from the perspective of the Swedish steel industry

Mowery and Rosenberg in their book *"Technology and the Pursuit of Economic Growth"*, show the very important role of the organisation of research and development for the innovation in the U.S.A. and various other countries. It is clear from this work that innovation is a condition for companies and countries to stay in the marketplace.

At the macro economic level, the intuitive believe of policy makers that there exists a direct relationship between the investment in R&D and the success in innovation, is supported by research findings. Rothwell and Zegveld show a Japanese statistic explaining the relationship between R&D investment and added value ratio (added value/shipped product value) for 28 industrial sectors in Japan (**Figure 12**). If the ratio of R&D to sales is an indicator for the technological intensity, then it is obvious from this graph that value added and technology are closely related.

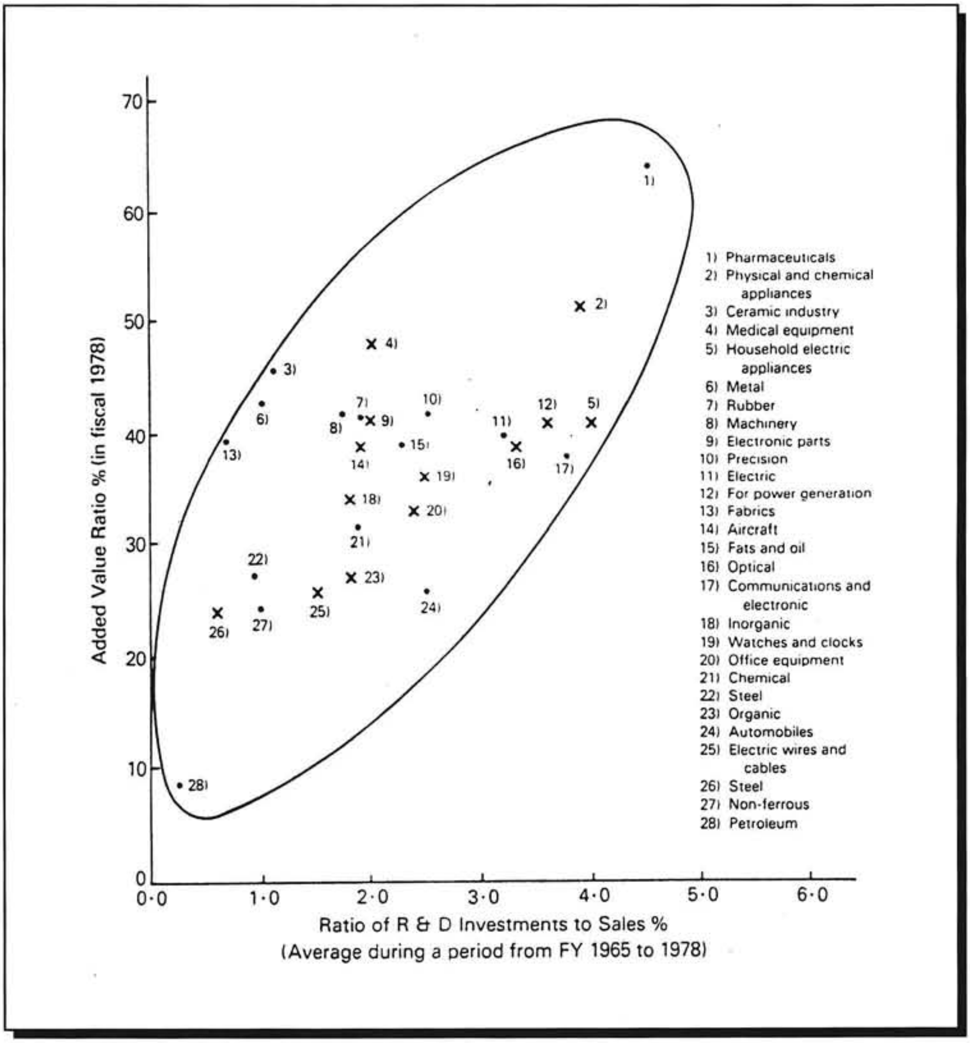


Figure 12: R&D investments and added value ratio

A more generalised innovation model is described in the report *"Innovation Activities and Industrial Structure"*. by T. Sandven and K. Smith. In this report it is

explained that applying economic indicators like percentage of R&D should be done against the background of the industrial structure of a country. It is clear that some sectors, like pharmaceuticals, require much more R&D in relation to sales volume than for example petroleum refining. **Figure 12** illustrates these differences clearly.
If a country has an industrial base that is dominated by low R&D intensive sectors, then a low percentage of R&D does not necessarily mean that the sectors are not able to innovate. R&D investments are thus always relative to the research needs of a particular sector. However, comparisons of one sector within various countries can be useful and meaningful. This is done in the study from A. Wyckoff, titled *"Investment, Innovation and Competitiveness; Sectoral Performance within the Traid"*.

Figure 13, Figure 14 show the R&D intensity ratios for the various countries. This ratio has been calculated as the 'ratio of business enterprise R&D expenditure performed in a manufacturing industry' over 'the production (gross output) of that industry for a given country or country groupings'.

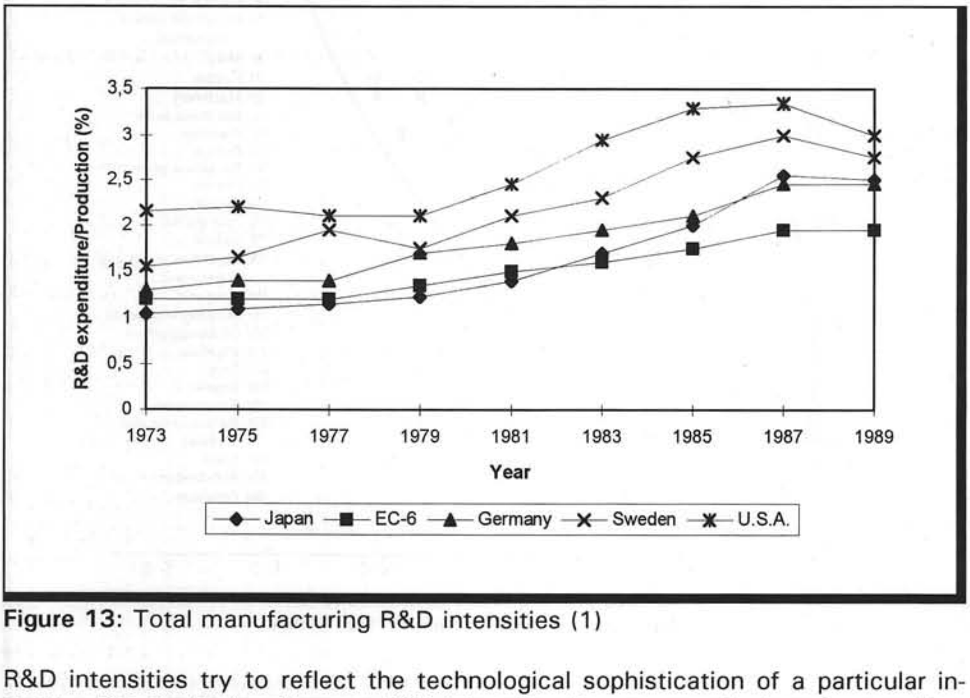


Figure 13: Total manufacturing R&D intensities (1)

R&D intensities try to reflect the technological sophistication of a particular industry. Despite their wide use, R&D intensities have many shortcomings as they account for only one (the need for a strong R&D effort) of the characteristics, usually attributed to industries considered as belonging in the high-technology category. Other characteristics of high-tech industries are the presence of high risks, large capital investment, very rapid product and process obsolescence,

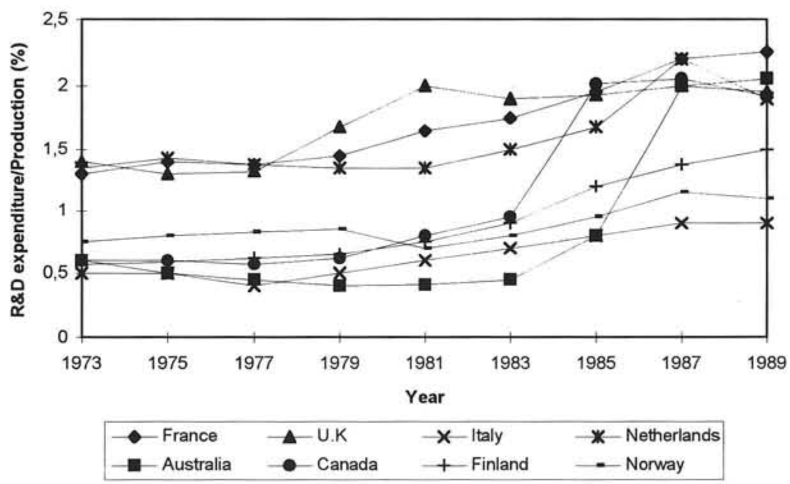


Figure 14: Total manufacturing R&D intensities (2)

strategic importance for governments and a high degree of international cooperation or competition in R&D.

In addition, by focussing exclusively on the R&D expenditures in a particular industry, no consideration is given to the fact that some industries often do little R&D themselves, but acquire embodied technology through the purchase of technologically sophisticated capital goods. In certain industries, like shipping, these alternative methods of acquiring technology may be more important than direct R&D expenditures; the R&D intensity ratios may therefore be a poor indicator for technological intensity of a sector.

Figure 15, Figure 16 show the R&D intensity ratios for the industrial sectors of the U.S.A. and Japan. From these graphs, it is evident that the high-tech sectors have the highest ratios. Its is also remarkable that even in Japan, shipping and shipbuilding are not identified as a separate industrial sector in this statistical analysis.

The U.S.A. and Japan are huge economies in comparison to for example the economies of The Netherlands and Norway. In the study of Sandven and Smith, the relationship between the size of the economy and manufacturing R&D intensities is investigated and shown in **Figure 17**.
The aggregate R&D intensities of all the industrial sectors within a country, does not do justice to the enormous variations between sectors, as already shown by the case of Japan (**Figure 12**).

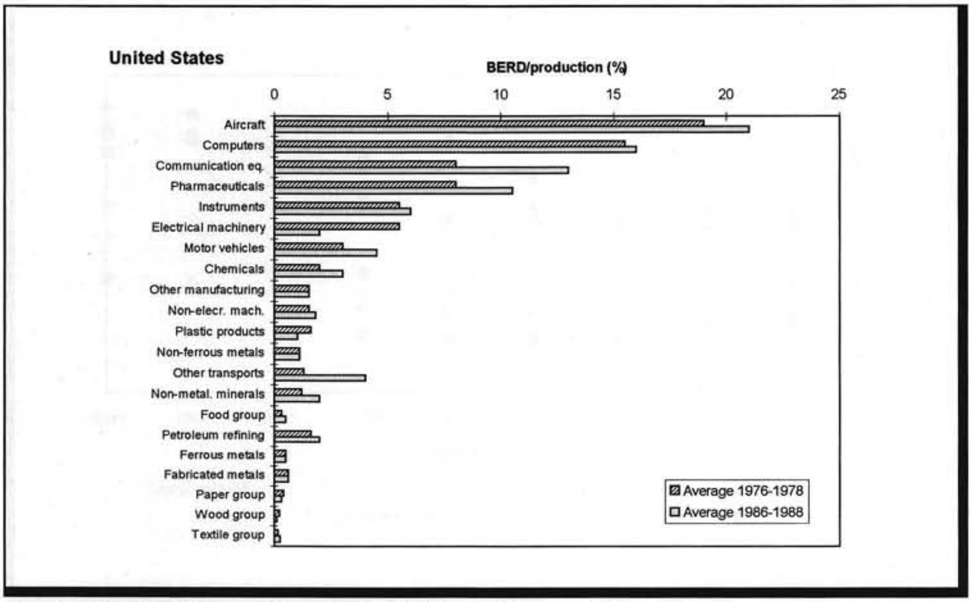


Figure 15: R&D intensity profiles, United States of America

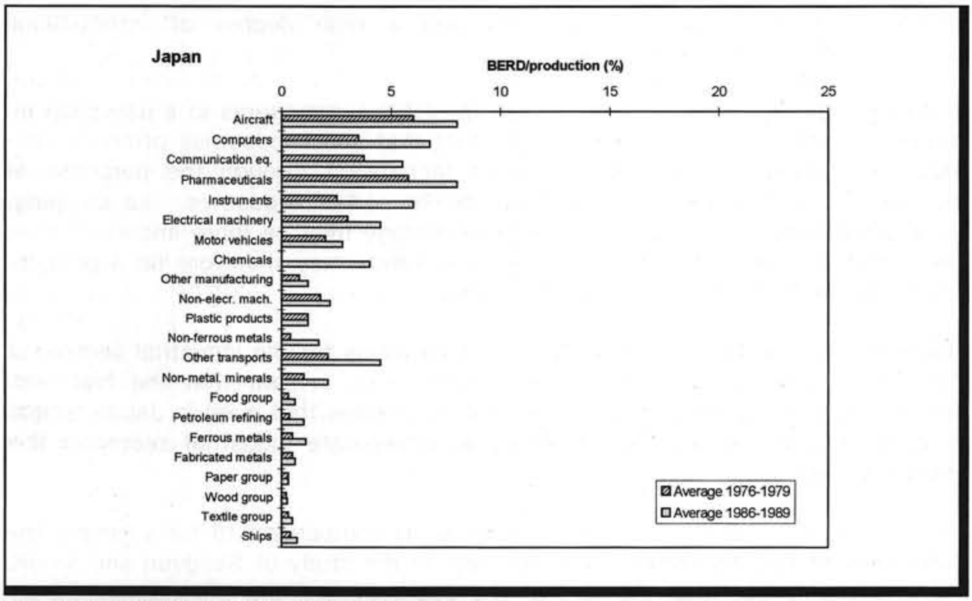


Figure 16: R&D intensity profiles, Japan

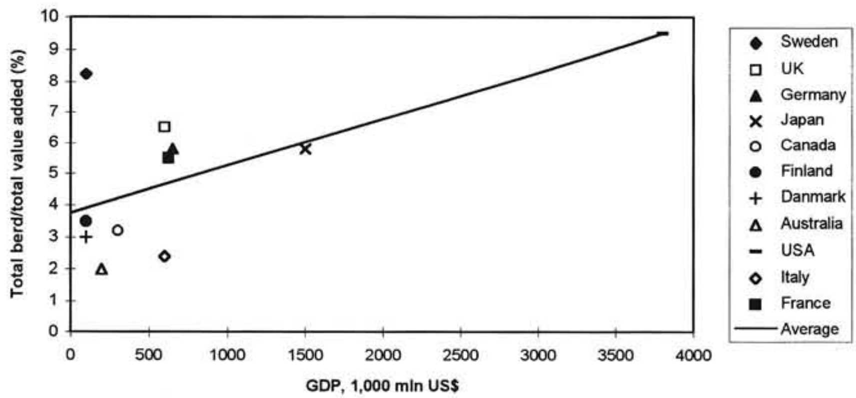


Figure 17: R&D intensity in manufacturing and size of economy, 1985

Figure 18 shows for 22 industries the relationship between the R&D intensities and the share of total manufacturing value added in Norway.
From this graph it is evident that large segments of the economy do not have a large R&D effort. Again, this may be justified in the light of the nature of the industrial activity.
Figure 19 shows the same industrial sectors and their R&D intensities for the total of 12 OECD countries: U.S.A., Japan, Germany, France, U.K., Italy, Canada, Australia, Denmark, Finland, Norway, Sweden.
Industries that have typically high R&D intensities are aerospace (no. 19), computers and office machinery (no. 14), communication equipment and semiconductors (no. 16), pharmaceuticals (no. 6), instruments (no. 21), motor vehicles (no. 18) and electrical machinery (no. 15). By contrast, important industries which typically have very low R&D intensities are food, drink and tobacco (no. 1), paper, print and publishing (no. 4), textile, footwear and leather (no. 2), and wood, cork and furniture (no. 3). Also shipbuilding (no. 17) is on average a low R&D intensive sector.

5.2.1 Research: basic definitions

In the previous section the words research and development have been frequently used, but not really defined. It is necessary to be precise in the definitions used. In the book *"The Economics of Industrial Innovation,"* the following definitions are given, which are schematically shown in **Figure 20**.

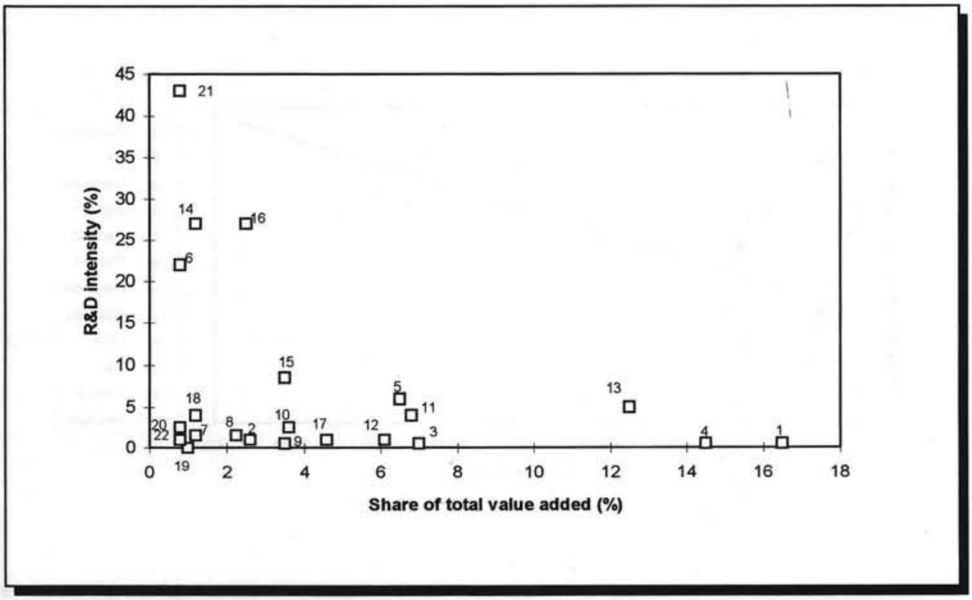


Figure 18: R&D intensity and total manufacturing value added, 1985 Norway

1	Food, drink and tabacco	12	Fabricated metal products
2	Textiles, footwear and leather	13	Non-electrical machinery
3	Wood, cork and furniture	14	Computers and office machinery
4	Paper, print and publishing	15	Electrical machinery
5	Industrial chemicals	16	Comm. eq. and semiconductors
6	Pharmaceuticals	17	Shipbuilding
7	Petroleum refining	18	Motor vehicles
8	Rubber and plastic products	19	Aerospace
9	Stone, clay and glass	20	Other transport equipment
10	Ferrous metals	21	Instruments
11	Non-ferrous metals	22	Other manufacturing

Table I: Explanation of the numbers in **Figure 18** and **Figure 19**

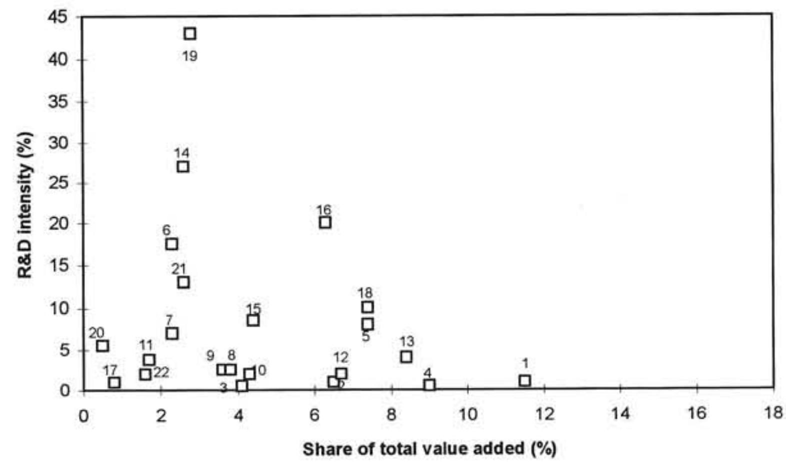


Figure 19: R&D intensity and total manufacturing value added, 12 countries

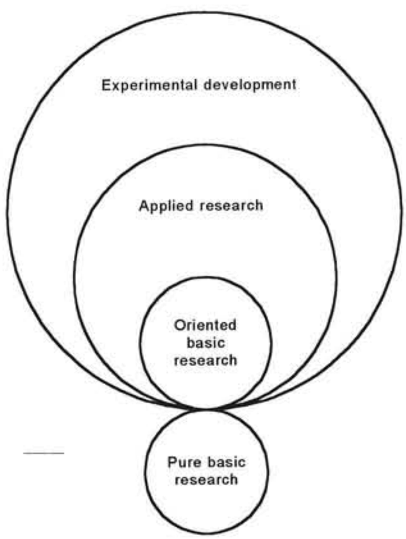


Figure 20: The measurement of scientific and technical activities

Basic research is originally investigation undertaken in order to gain new scientific knowledge and understanding. It is not primarily directed towards any

specific practical aim or application. Basic research yields new hypothesis, theories and general laws.
In *pure* basic research it is generally the scientific interest of the investigator that determines the subject studied. In *oriented* basic research the organisation employing the investigator will normally direct his work towards a field of present or potential scientific, economic or social interest.

Applied research is also original investigation undertaken in order to gain new scientific or technical knowledge. It is, however, directed primarily towards a specific practical aim or objective. The results of applied research are intended primarily to be valid for a single or limited number of products, operations, methods and systems.

Experimental development is the use of scientific knowledge in order to produce new or substantially improved materials, devices, products, processes, systems or services. It is systematic work, drawing on existing knowledge gained from research and or practical experience.

5.3 Forces on innovation

What is the driving force behind innovation? At the company level, it its the pure survival of the firm against the (international) competition. In the absence of competition, there is no basic incentive to innovate for the individual firm. This situation existed in many of the former centrally-planned economies with monopolistic market conditions.
In a market economy, companies have to stay ahead of their competitors by increasing product/service quality and lowering product/service cost. This results in a relentless search for new technologies and innovations, as best conceptualised by the so-called *product life cycle* (**Figure 21**).

This curve shows the variation over time of the volume of sales of a new product or service. The product itself passes through a period of adaptation and improvement. After the initial group of users have diffused the benefits of the products to a wider group of potential users, the sales volume starts to increase rapidly and the product is further enhanced. This is called the growth phase, which is eventually followed by market saturation and a leveling off of demand: the product enters its maturity phase. Ultimately, sales decline as other more competitive products gain market share and this will lead to the end of the product life cycle.
Most of the known products and services can be translated into this conceptual model. It is therefore very often used by managers to anticipate change in their markets, and to direct innovation and R&D efforts.

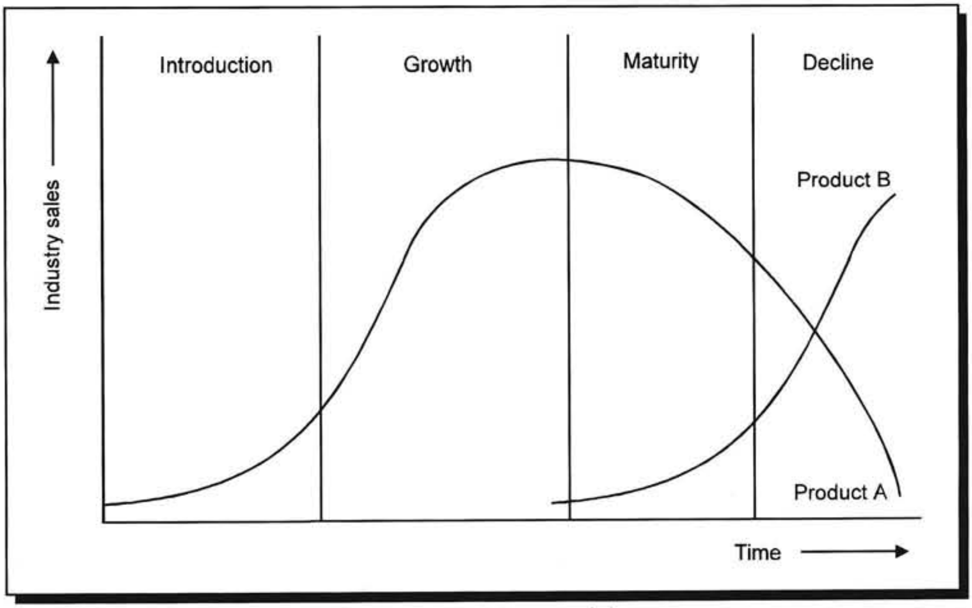


Figure 21: The product life cycle: four-phase model

Figure 22 and **Table II** shows another conceptual model, which is more technologically specific. According to this model, as a major new class of products emerges, the emphasis of technological development shifts from one of major *product* innovation to one of *process* innovation and minor product improvement.

The product life cycle model and the product/process cycle model have clear implications for the competitive strategies of industrial companies. Both imply that competitiveness is linked, in the first instance, to market-oriented product innovation, and that continued competitiveness and sales are linked to continuous innovations affecting both product performance and manufacturing process efficiency. Eventually all products tend to become obsolete.

This is clearly demonstrated by **Figure 23**, taken from *"The Global Challenge of Innovation"*. The graph shows the number of steam-driven and diesel-driven locomotives in use in the United Kingdom and the U.S.A. over the long period of more than hundred and forty years (1835-1975). Once the diesel engine reaches a high quality standard, the decline of the steam engine is inevitable.

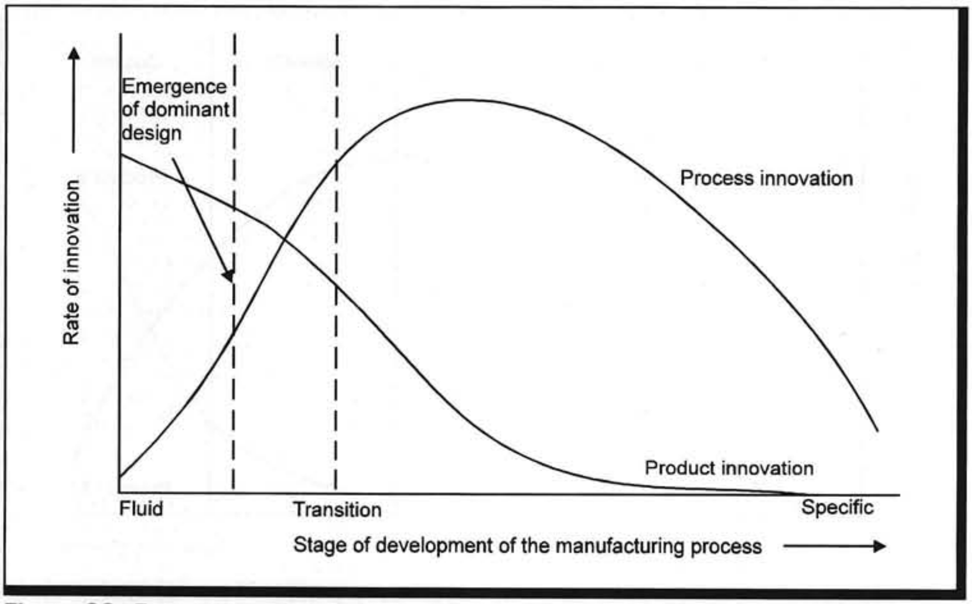


Figure 22: Frequency of product and process innovations

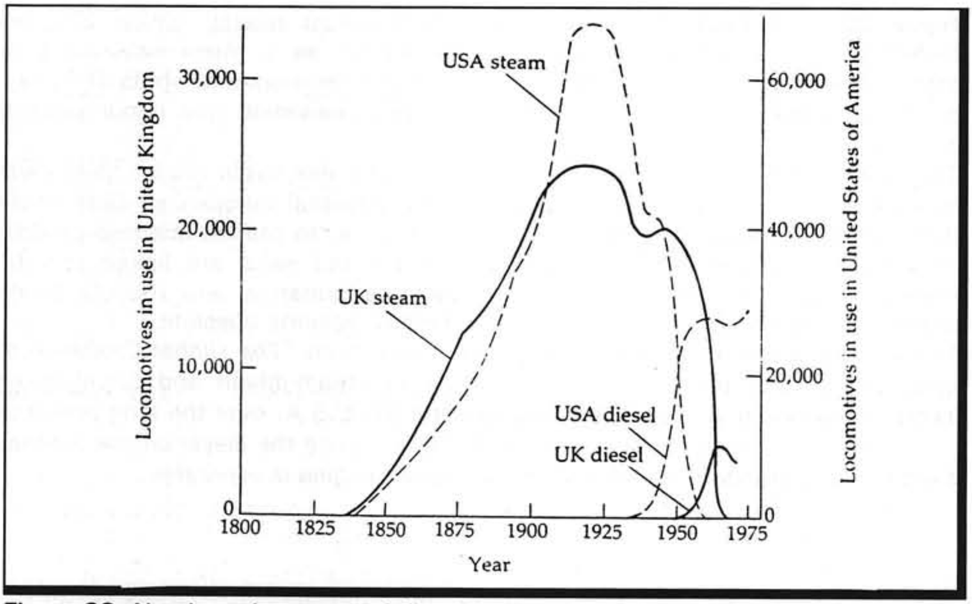


Figure 23: Number of steam and diesel locomotives in service

	Fluid pattern	Transitional pattern	Specific pattern
Competitive emphasis on	Functional product performance	Product variation	Cost reduction
Innovation stimulated by	Information on users' needs and users' technical input	Opportunities created by expanding internal technical capability	Pressure to reduce cost and improve quality
Predominant type of innovation	Frequent major changes in producs	Major process changes required by rising volume	Incremental for products and process, with cumulative improvement in productivity and quality
Product line	Diverse, often including custom design	Includes at least one product design stable enough to have significant volume	Mostly undifferentiated standard products
Production processes	Flexible and inefficient; major changes easily accommodated	Becoming more rigid, with changes occurring in major steps	Efficient, capital-intensive and rigid; cost of change is high
Equipment	General-purpose, requiring highly skilled labour	Some subprocesses automated, creating 'island of automation'	Special-purpose, mostly automatic with labour tasks mainly monitoring and control
Materials	Inputs are limited to generally-available materials	Specialised materials may be demanded from some supplier	Specialised materials will be demanded, if not available, vertical integration will be extensive
Plant	Small-scale, located near user or source of technology	General-purpose with specialised sections	Large-scale, highly specific to particular products
Organisational control is	Informal and entrepreneurial	Through liaison relationships, project and task groupes	Through emphasis on structure, goals and rules

Table II: Frequency of product and process innovations

Figure 24 and **Figure 25** illustrate the use of the life cycle diagram in yet another way. **Figure 24** shows the different sectors of the Dutch economy, their relative contribution to the value added, and the phase on the sectoral life cycle.

Figure 25 illustrates its use in yet another way, the policy analysis life cycle. On the vertical axis, the political weight of the policy issue is plotted against the life cycle of the policy relevance of the issue; this diagram made by the former minister of environmental affairs, Dr. P. Winsemius, shows that when a new issue emerges, most of the parties involved disagree about the relevance of the issue and the weight that should be attached to it in order to solve it. Gradually, the

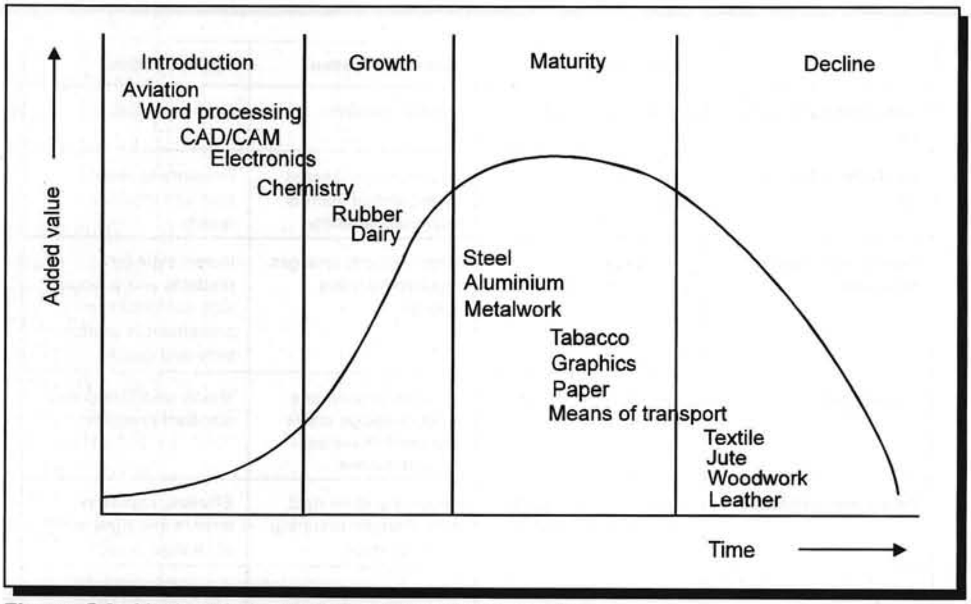


Figure 24: National profile from The Netherlands

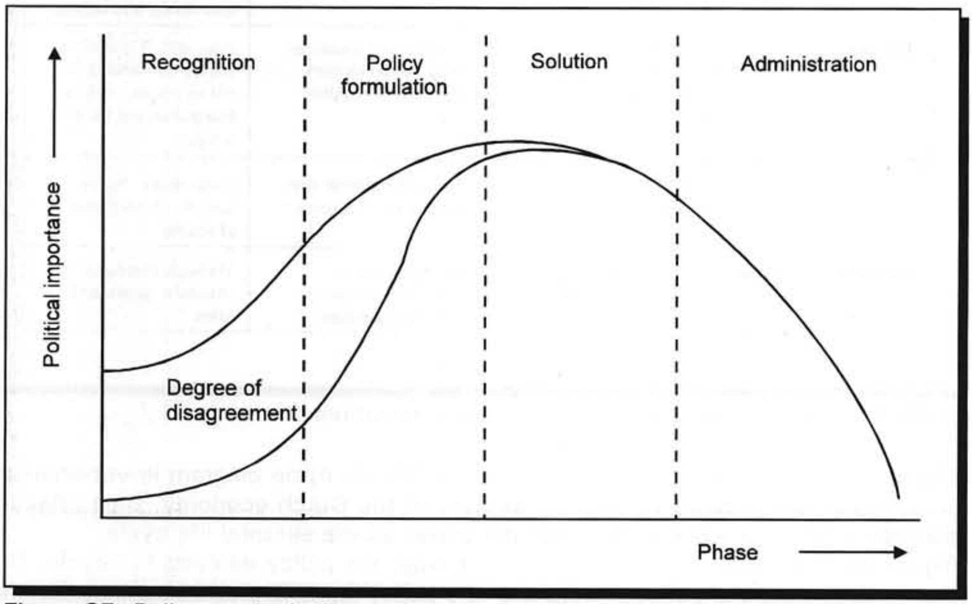


Figure 25: Policy analysis life cycle

consensus grows, and the debate changes form antagonism to cooperation, which marks the end of the life cycle.

The life cycle concept has also been applied to the cruise market by the former Finnish yard Wärtsila (now Kværner Masa-Yards). **Table III** shows the segmentation of the *cruise market life cycle* and the segments that are emerging fast growing, slowly growing, mature and declining (1985). The shipyards and cruise ship owners use this model to develop new ship concepts in order to cater for these new markets.

Fast ships, in particular hydrofoils started to appear in the passenger markets in the early sixties. This ship type was successful in a number of markets, especially where a relatively calm sea prevailed, due to the limited seakeeping capabilities of these ships in heavy weather. Therefore, new fast ship concepts were developed in Europe, based on catamaran and other hull forms. A similar, but more voluminous development took place thereafter in the Far East. Recently the market of pure fast passenger ships was expanded with a new category, the fast combined passenger and car ferries. The question now is whether the fast ship concept will be extended to pure freight vessels, such as proposed by the German yard Blohm & Voss (see section 7.2). The successive product life cycle developments in fast ships are schematically represented in the **Figure 26**.

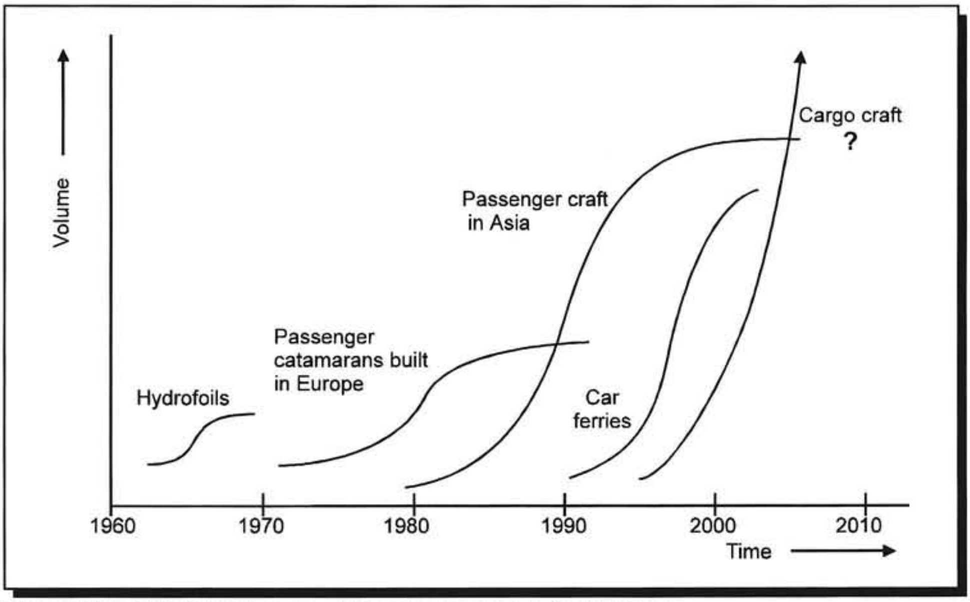


Figure 26: HSLC S-Curves *(Source: Det Norske Veritas)*

Success factors

Emerging	**Fast growth > 10%**	**Slow growth < 10%**	**Maturity**	**Decline**
- Choose the right technology - Capture market - Creativity - Timing - Entrepreneur-ship	- Low price - Standard product - Reliable product - Fast reaction to the increas-ing demand - Establish marketing and sales channels	- Response to new market needs - Right product - Image - Investment control - Fast reaction to changes in the market - Agressive marketing	- Staying power - Cost mini-misation - Investment control - Niches	- Protection of market shares - Milk the market - Exit timing
Typical ships - Small or handy size - New technol-ogy - Replaced old tonnage	- Conversions - Lengthening - ' Weak signal' new buildings	- Tailor-made ships - Economy of scale	- Fleet integra-tion -New technol-ogy	- Retrofit

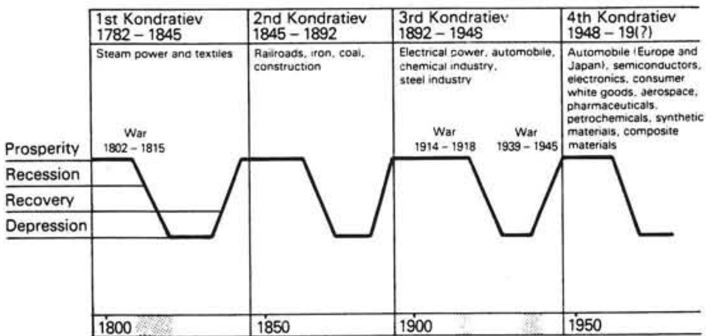
Markets

Emerging	**Fast growth > 10%**	**Slow growth < 10%**	**Maturity**	**Decline**
- Pacific island cruises - ' Cruises to nowhere' - One-night cruises - Expedi-tion/special **New technology** - Wind cruiser - Pax/contianer - SWATH **New passenger target groups** - Japan - Far East	- Caribbean 'fun' cruises - West Coast 'fun' cruises - Small Cruise ships ' yacht cruisers' - American flag a) Retrolit big ships b) 100 GRT small coas-tal vessels - European cruise ferries - Mediterranean - China	- Caribbean 7 days - Alaska - Trans canal - North cape - Baltic - Australia	- Round-the world cruises - Bermuda - Caribbean 14 days	- Ocean liners for passenger transport - Mediterranean cruising in second-hand ships

Table III: The cruise market

5.4 Business cycles and innovation

The product and process life cycle concepts lead us to the issue of fundamental economic changes over longer periods of time, as analysed and documented by the Russian economist N.D. Kondratiev. He based his theory on an analysis of the price and production time-series data and identified three cycles or waves of economic recession, depression, recovery and prosperity with a period of some 55 years. **Figure 27** shows a simple schematic representation of the *Kondratiev Waves (Source: Rothwell & Zegveld)*.



Prosperity	1782 – 1802	1845 – 1866	1892 – 1913	1948 – 1966
Recession	1815 – 1825	1866 – 1873	1920 – 1929	1966 – 1973
Depression	1825 – 1836	1873 – 1883	1929 – 1937	
Recovery	1836 – 1845	1883 – 1892	1937 – 1948	

Figure 27: A simple schematic of the Kondratiev Waves

While Kondratiev did not explicitly include technology as a causal factor in long-wave formation, he did suggest that when a major wave of expansion occurred, inventions that had remained dormant, would attract investment and begin to find commercial application.

It was J. Schumpeter who stressed the notion of radical technological innovations as a major factor in the recurrent crisis of structural adjustment. The decline of the role of canals and horses in transportation and the rise of the railways is an obvious case. It is followed by the rise of the internal combustion engine (road transport) and the decline of the railways.

Innovations that would cause Kondratiev-type waves, had to be dramatic in their economic and social impact. Schumpeter pointed to such major innovations:

- Textiles and related innovations, which he associated with the First Wave;
- Railways, iron, coal and construction, which he associated with the Second Wave;
- Electrical power, the chemical industry and automobiles, which he associated with the Third Wave.

The Fourth Wave started in 1948, and many researchers have tried to answer the question about the role of technological change and the structural changes that have occurred since then. The most notable feature of the past decades has been the emergence and rapid growth of a bunch of new technology-based industries. These are associated with advances in science and technology of the previous twenty years or more, notably electronics, semiconductors, synthetic materials, petrochemicals, agrochemicals, composite materials, pharmaceuticals and aerospace.

There is probably no market as cyclical as shipping. M. Hampton has tried to explain the waves in shipping (freight) markets, especially those of tankers and bulk carriers. Het has come up with the theory of short and long shipping cycles. The short cycles last 3 to 4 years and the long cycles 20 to 25 years (**Figure 28**). The long cycle consists of a buildup phase and a correction phase, which both lasts 8-12 years. Hampton's thesis is that in shipping the business cycles are not so much determined by the real economy, but rather by the psychology of the players in the market, such as shipowners, investors and financiers. He has given the different stretches of the cycle very suggestive names, such as the last big expansion cycle that he named the "*suckers rally*". With this name he tries to coin the policy of bank lending for ships only when the market is at its peak. Hampton has applied his wave concept to the tanker and bulk markets, and has identified a number of waves since 1947, which are shown in **Table IV**.

Although it is easy to question the correctness of the long cycle theory, it is a very useful instrument to relate shipping to innovation. The model shows prolonged periods of very bad shipping markets, in which the freight rates are so low that the owner can hardly cover his variable costs. In those periods, the need for innovation (lowering cost and increase competitiveness) and the willingness of owners to invest in surplus capacity is so low that there is no incentive for innovation. Contrary, periods of buoyant freight markets that lead to capacity expansion or fleet renewal, are the periods during which innovation takes place.

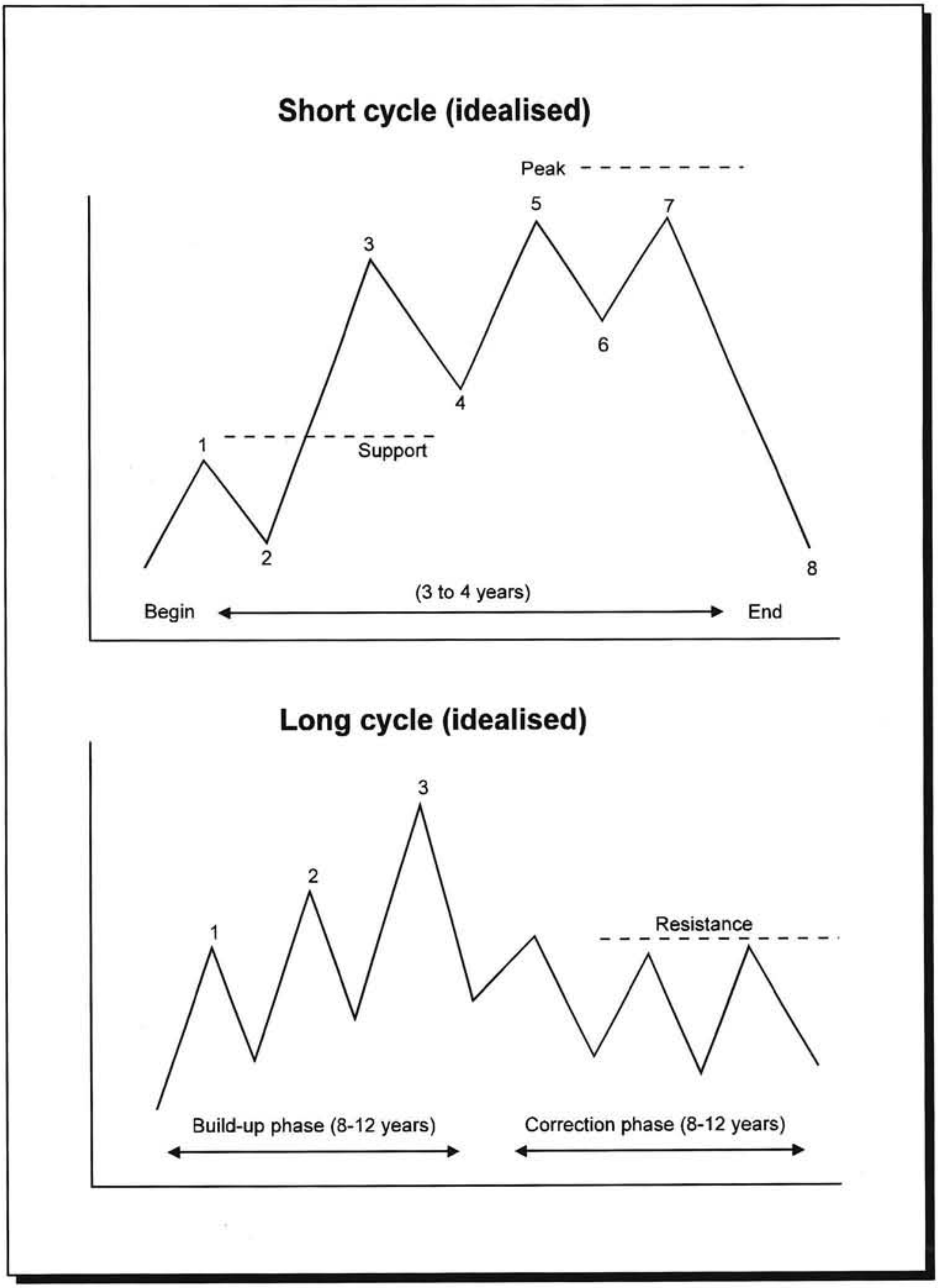


Figure 28: Idealised cycles in shipping

	Tankers Timing	Dry bulk Timing
Build-up		
Peak 1	1947/48	1947
Low	1949	1949
Peak 2	1951/52	1951/52
Low 1954	1953	
Peak 3	1956/57	1956/57
Correction		
Low	1958	1959
Rebound	1960	1961
Low	1961	1962
High 4a	1963	1965/66
Low	1964	1966/67
High 4b	1965	1967
low 1967	1968/1969	

	Tankers			Dry bulk		
	Level	Timing	Delay	Level	Timing	Delay
Build-up						
Peak 1		1967			1970	
Low		1969			1972	
Peak 2		1970			May. 74	
Low		1972			Aug. 77	39 Mos.
Peak 3	31.11	Sep. 73		2,268*	May. 80	33 Mos.
Correction						
Low	2.66	May. 75	20 Mos.	847*	Jul. 82	26 (19)*
Rebound	5.45	Nov. 76	17 Mos.	1,081*	Apr. 84	21 Mos.
Low	3.48	Jun. 78	20 Mos.	554	Jul. 86	27 Mos.
High 4A	12.29	Dec. 80	30 Mos.	1,649	Mar. 88	20 Mos.
Low	4.67	Mar. 82	15 Mos.			
High 4B	13.58	Jul. 84	28 Mos.			
Low	5.67	Jul. 85	11 Mos.			

* Based upon the Montly Average of the Baltic Freight Index since June 1984. Prior to that, data is from a 'reconstruction'provided by E.D. & F. Mann's Shipping Affiliate.

Table IV: Cycle patterns in tanker and bulk market

5.5 The competitive development of national economies: innovation stage

Economic prosperity of a country depends on the productivity with which national resources are employed. The level and growth of productivity are a function of the array of industries and industry segments in which a nation's firms can successfully compete, and the nature over time of the competitive advantages achieved in them. Economies progress by upgrading their competitive positions, through achieving higher-order competitive advantages in existing industries and developing the capability to compete successfully in new, high-productivity segments and industries.
According to M. Porter, national economies go through a number of stages of competitive development. These reflect the characteristic sources of advantage of the firms of a nation in the international competition. They also reflect the nature and extent of internationally successful industries and clusters.
Despite the diversity of most economies, a pattern in the nature of the competitive advantage of a country over time can be identified. Porter distinguishes in four stages of national competitive development: *factor-driven, investment-driven, innovation-driven,* and *wealth-driven*. They are illustrated schematically in **Figure 29**.

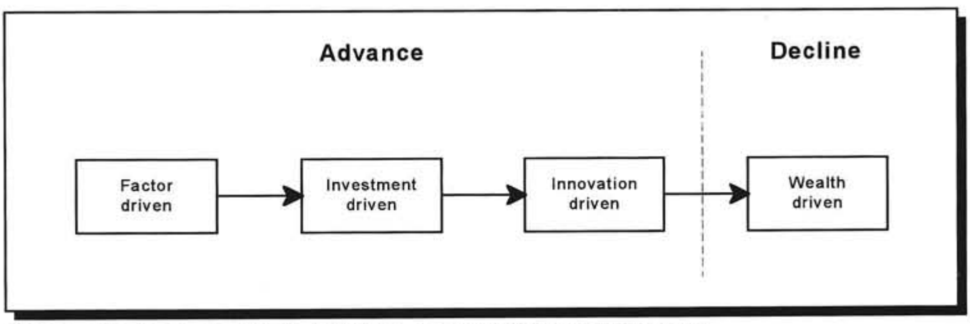


Figure 29: Four stages in national competitive development

The first three stages involve successive upgrading of a nation's competitive advantages and will normally be associated with progressively rising economic prosperity. The fourth stage is one of drift and ultimately decline. The different stages will be discussed with the help of Porter's conceptual model of the dynamics of national advantage. This model is useful in order to understand the basic determinants of the national advantage, and has been given the name *Diamond* (**Figure 30**).

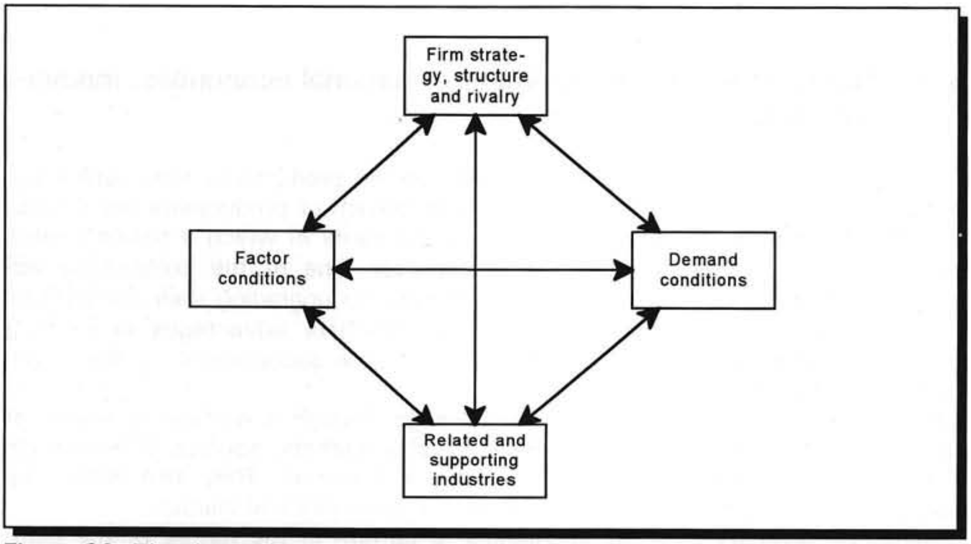


Figure 30: The determinants of national advantage

Stage 1: Factor-driven

In nations at this initial stage, virtually all internationally successful industries in the country draw their advantage almost solely from basic factors of production, whether they are natural resources, favourable growing conditions for certain crops, or an abundant and inexpensive semiskilled, low cost labour pool.
This source of competitive advantage limits sharply the range of industries and industry segments in which a nation's firm can compete in international terms. In such an economy, the local firms compete solely on the basis of price in industries that require little product or process technology or technology that is inexpensive and widely available. Technology is sourced largely from other nations and not created within the country.
In this first stage of economic development, an economy is sensitive to world economic cycles and exchange rates, which drive demand and relative prices. The possession of abundant natural resources may support a high per capita income for a sustained period of time, a factor-driven economy is one with a poor foundation for sustained productivity growth.

Stage 2: Investment-driven

In this stage, national competitive advantage is based on the willingness and ability of a country and its firms to invest aggressively in modern plant and equipment, based on the best technology in the world market. The country's earnings are also invested in the upgrading of the physical and human infrastructure. In this stage the foundation is laid for the next stage, Innovation-driven, which is of main interest in the context of this book.

Stage 3: Innovation-driven

In the innovation stage, the full *Diamond* is in place in a wide range of industries. The mix of industries and segments in which the nation's firms can successfully compete, broaden and upgrade. Consumer demand becomes increasingly sophisticated because of rising personal incomes, higher levels of education, and the stimulating role of domestic rivalry amongst the firms. The growing competitive strength of the firms in a range of industries also leads to the emergence at home of sophisticated industrial customers. New entrants accelerates product and process improvement and innovation. World-class supporting industries develop in the important clusters, while competitive industries emerge out of related industries.

This stage of economic development is called innovation-driven because firms not only appropriate and improve technology and methods from other nations, but also create them. The capacity to innovate opens up yet more new industries.

Stage 4: Wealth-driven

Nations pass through the first three stages of competitive development if they can sustain a dynamic process of upgrading national advantage. This involves the move to more sophisticated competitive advantages and the widening of the range of industries in which the firms can successfully compete. In the process, positions in less advanced, lower productivity segments are lost.

The wealth-driven stage is, in contrast, one that ultimately leads to decline. The driving force in a wealth-driven economy is the wealth that has already been achieved. The problem is that an economy driven by past wealth is not able to maintain its wealth. In this stage, firms begin to lose competitive advantage in international industries for a variety of reasons.

CHAPTER 6: COMPETITIVE ADVANTAGE AND INNOVATION IN SHIPPING

Porter's conceptual models of the four stages of economic development and the structure and determinants of the competitive advantage, are useful tools for understanding innovation in the economy, also in shipping. A number of studies has been made in Norway and The Netherlands in which it is attempted to apply these models to the shipping reality. This chapter summarises these studies.

6.1 Yacht building in The Netherlands

In the study *"The Economic Strength of The Netherlands: An Application of Porter's Approach to the Competitive Advantage of Nations"*, the authors have selected eleven successful Dutch industrial and service sectors with different economic importance to the Dutch economy. The selection criterion is the sustained success of these sectors in the international marketplace, measured by the share of exports as percentage of the total sales volume.

One of these successful sectors is the yacht building industry. In 1990, the sales of the sector was NLG 850 million, and exports accounted for more than fifty percent of sales. The Dutch yacht production (number) over the period 1988 - 1991 is shown in **Table I**

	1988	1989	1990	1991
Number of yachts built	3815	4850	5110	5492
Foreign sales	2033	2582	2595	2699
Home sales	1782	2268	2515	2793

Table I: Yacht building in The Netherlands; sales and production

The almost 5500 yachts built in 1991, are produced by a staggering 500 companies, of which 15 firms are large, 85 are medium-sized and the remainder is small; the employment in the sector is approximately 5000.

The 15 leading companies (1500 employees) determine the high-quality image of the Dutch yacht building. They build very expensive yachts for an exclusive international clientele. The smaller yachts are also made to order, but are based on standard designs. The Dutch yacht makers are strong in a number of segments: steel hull motor yachts, aluminium sailing yachts, small steel standard motor yachts and many small polyester sailing yachts.

The result of the application of Porter's diamond model to the yacht sector, resulted in the diagram as shown in **Figure 1**. The individual determinants will be briefly discussed.

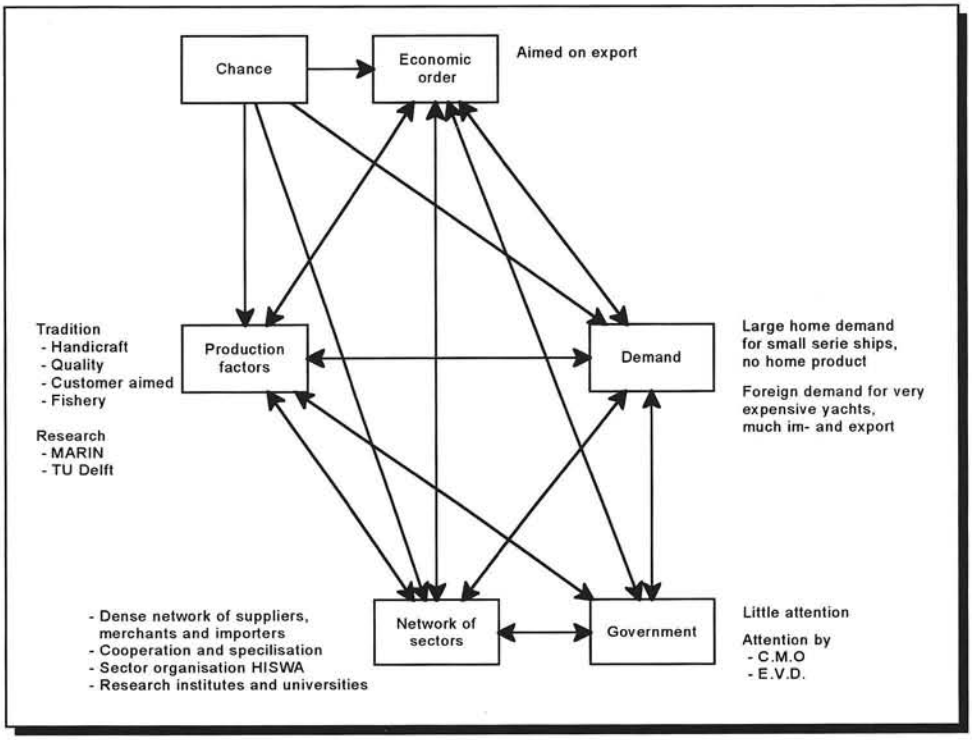


Figure 1: Porter's diamond model to the yacht sector

Factor conditions

The Netherlands have a long tradition in shipping and shipbuilding. The important factor conditions are based on the Dutch tradition of labour skills (handicrafts) and quality, commercial spirit and a client-orientation. The origin of many yacht builders can be traced back to the time of fishing vessels construction. As the demand for these kind of small vessels disappeared, the yards switched to yachts.

The sector employs a relatively low-skilled workforce that is mainly schooled in-company. The entrepreneurs in the sector usually have a similar vocational background.

The maritime research institutes, also at the university, provide the knowledge and facilities that are typically required by the designers and builders of yachts. A lot of new knowledge enters the yards via the exchange of information with the other suppliers in the network.

Demand conditions

The Netherlands have a long relationship with water, as half of the country is protected by dikes against the sea and the rivers. This was a fertile basis for a pleasure craft industry, which started already in the 17th century with sailing races on the lakes. Consequently there exist many marina's (1000) and dedicated infrastructure for the motor and sailing yachts. There are 220,000 yachts in The Netherlands, which equates to the highest per capita yacht density in the world. The domestic demand is limited to the lower end of the market. The top-segment originates mainly from abroad.

The network

The yacht builders use an extensive network of suppliers, which import the parts and equipment from abroad. This network is, in comparison with other countries, very dense. Some suppliers have developed a worldwide supply role based on the initial demand in The Netherlands and a market niche strategy, for example in sailing masts, or precut steel/aluminium. There is a development towards further specialisation within the network, whereby suppliers work for all the yards, for example in the field of painting, interior and electrical work.
The presence of many naval architects is also an important strength within the network, just as the presence of the major classification societies. The yacht brokers cement the industry together as they create liquidity in the secondhand market, which is important for renewal of the sector. Finally, the industry institute called HISWA, is the uniting factor within the yacht sector and creates a platform for contacts with buyers and suppliers.

Firm strategy, structure and rivalry

The competition in the sector is strong, although the major yards have created a market niche for themselves that shields them partly from competition. The yards have attempted in the past to cooperate more closely, but most of the initiatives have shipwrecked.
Government interference in the sector has been absent. The yacht builders do not receive any subsidies, but occasionally there is some support for research or export promotion.

Conclusion

The Dutch yacht sector is especially innovative and competitive in the upper segment of the market. The high-quality image shines on to the lower segments. There is a diversified and dense network of (international) suppliers service providers. The industry organisation develops many initiatives to create dynamics in the sector and diffuse innovation and knowledge. This is of importance to the smaller builders with hardly any overhead. The strong export position and the value added by the sector should warrant a stronger government support. The knowledge base should be strengthened.

6.2 Heavy lift shipping in The Netherlands

6.2.1 Introduction

Through the ages The Netherlands always had a strong position in the shipping industry. With the rise of many other countries in shipping, The Netherlands have lost a great share of their former market position. However, there are still sectors in which the Dutch are dominant and one of them is the heavy lift shipping.

This section explores the reasons behind this succes, using the Porter methodology. It is based on the situation in the heavy lift shipping industry as it was in the year 1993 and is based on a special course at the Falculty, see Chapter Notes. Since then, important changes have occurred. A merger has taken place between two important Dutch heavy lift companies and the resulting company has registered in Belgium, though this company is still Dutch owned.

6.2.2 The heavy lift market

It is difficult to define when shipping is *heavy lift shipping*. One definition can be "*the transport of pieces of cargo that have a mass of more than 60 tonne, and that are difficult to manage, often vulnerable and/or voluminous*"

The heavy lift shipping finds its origin in the tug and tug/barge method. The heavy lift had its own buoyancy and was towed, or was loaded on a large barge and then towed to, its destination. With the rise of the dredging, chemical and offshore industry comes the demand for transportation of heavy cargoes and specialised ships. The first heavy lift vessels were built for this purpose. Today the chemical and offshore industry are still major clients of the heavy lift market.

The fleet of heavy lift ships can be divided into 3 segments:

- *Conventional heavy lift ships*
  The conventional heavy lift vessels is equipped with at least one heavy crane to take the heavy cargo aboard according to the lift-on lift-off principle. The ships are equipped with enough ballast capacity to ensure safe stability and satisfying seagoing behaviour.

- *Semi-submersibles*
  This type of ships does not have the crane capacity like the conventional heavy lift ships. They work according to the float-on float-off principle.

The ship takes ballast to get the required draugth. Then the cargo is positioned above the ship and the ballast tanks are emptied, so the ships rises again.

- *Dock lifts with heavy cranes*
  This ship is a combination of the two previous types. The ship can load its cargo according to the float-on float-off principle, but also has heavy cranes that are able to handle the cargo.

Figure 2 to **Figure 5** illustrate the different concepts

In 1992 there were four Dutch companies specialised in heavy lift shipping. These companies were:

- Dock Express;
- Jumbo Navigation/Kahn;
- Mammoet Shipping;
- Wijsmuller Transport.

At the same time there were 9 shipowners from other countries operating in the heavy lift market. The total world fleet consisted of 78 vessels with a total deadweight of 793,243 tonne. 40 ships, with a total deadweight of 467,576 tonne, were owned by the four Dutch companies. This is respectively 51.3% and 58.9% of the entire world fleet. **Table II** shows the shipowners and their fleet.

The heavy lift transport sector can be divided into four main categories:

- *Offshore*;
  These are: Jack-up rigs, semi-submersible rigs, work barges, offshore modules, drill tenders, jackets and mooring systems.
- *Maritime infrastructure*;
  These are: Dredging equipment, dry docks, bridges, tunnels, container cranes/transtainers and floating cranes.
- *Industrial infrastructure*;
  These are: Onshore modules, floating plants.
- *Others*;
  These are: Floatels, accommodation units, various float and non-float, time charters and dry docking facilities.

Each Dutch company has its own specialisation. Dock Express Shipping is specialised in maritime infrastructure such as container cranes, Jumbo Navigation and Mammoet Shipping are specialised in industrial infrastructure and Wijsmuller Transport is specialised in the offshore segment.

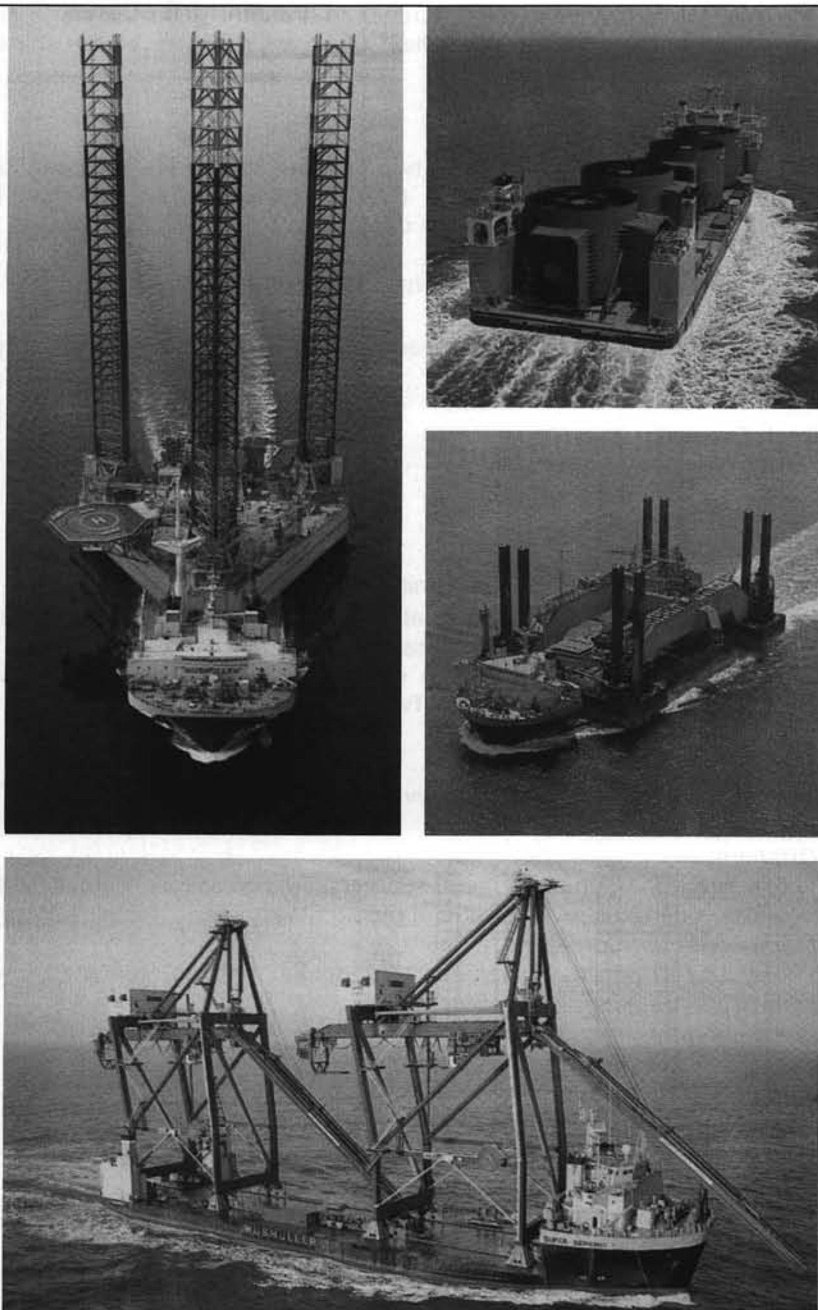


Figure 2

Figure 3

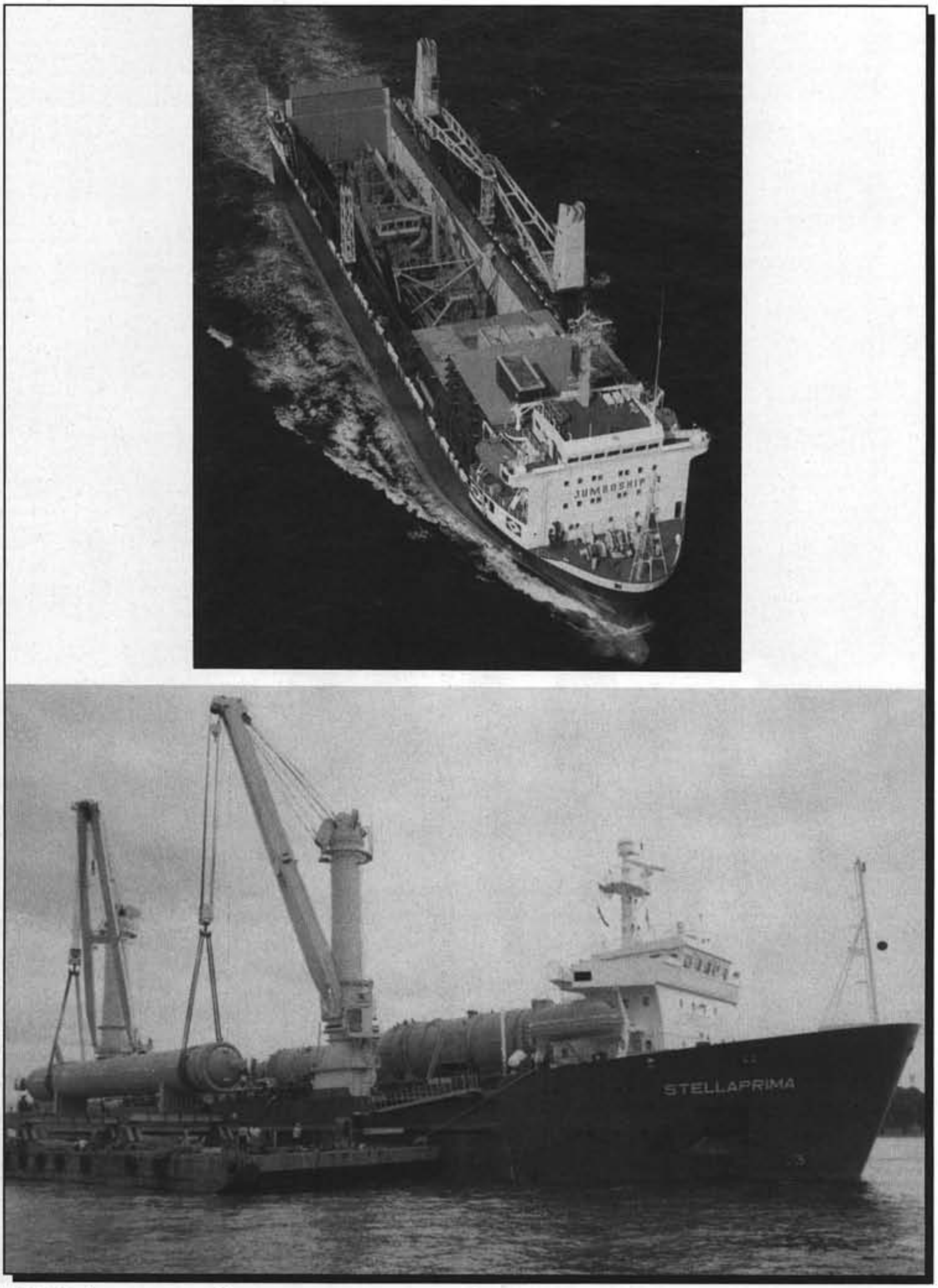


Figure 4

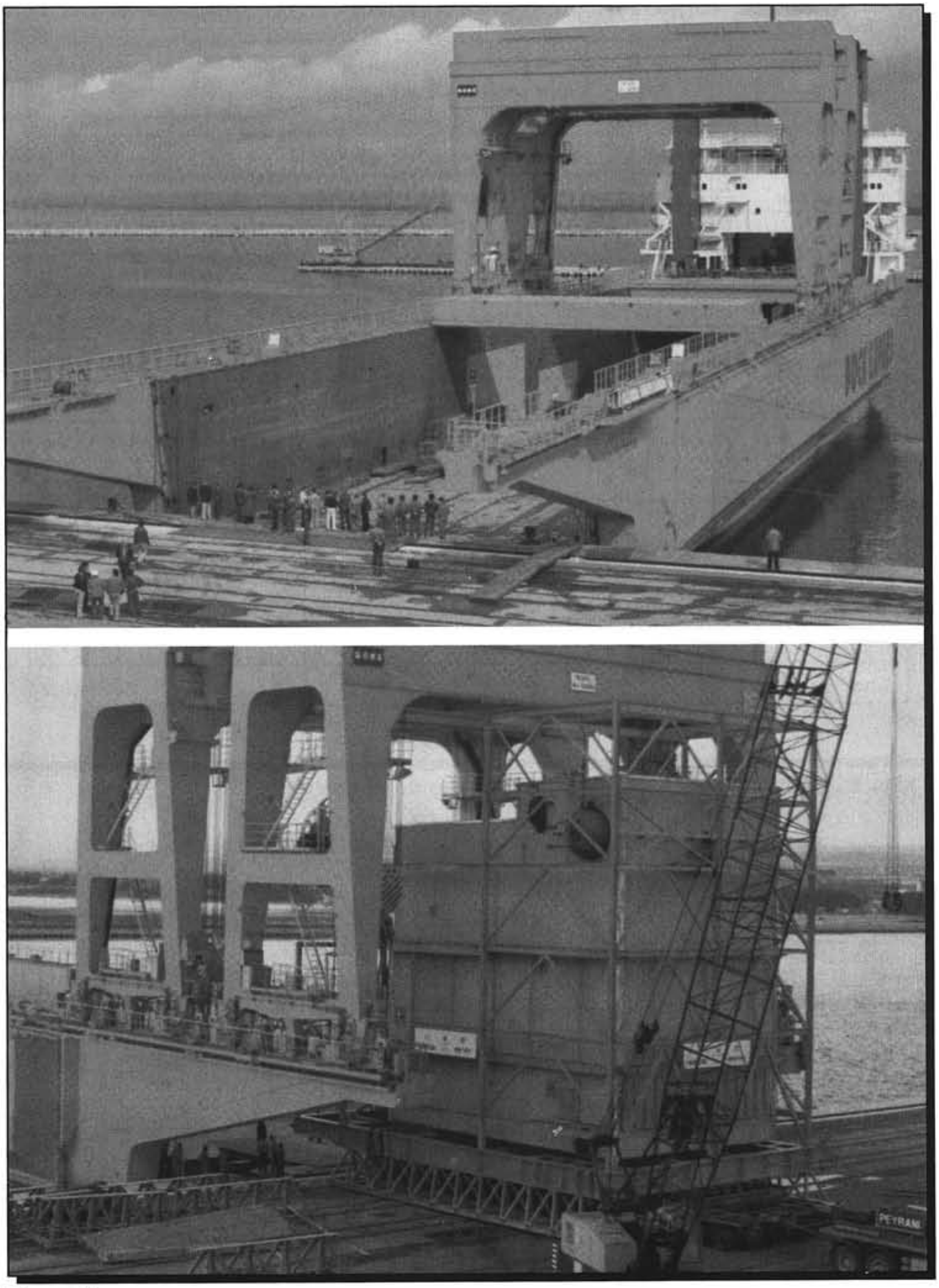


Figure 5

Company	Nr of ships	Total deadweight (tonne)	Average deadweight (tonne)	Total crane capacity (tonne)	Total deck area (m^3)
Wijsmuller	*12*	*189,723*	*15,810.3*	*2,850*	*42,092.8*
Jumbo/Kahn	*11*	*57,400*	*5,218.2*	*6,100*	*9,924.5*
Mammoet	*12*	*145,613*	*12,134.4*	*6,488*	*21,480.0*
Dock Express	*5*	*74,840*	*14,968.0*	*5,000*	*14,510.0*
SAL	9	60,787	6,754.1	2,400	8,520.9
Contimar line	2	11,800	5,900.0	270	1,619.2
Consolidated Pool	4	29,184	7,296.0	800	3,608.4
Condock	5	20,600	4,120.0	698	6,153.0
Hinode Kisen	6	120,273	17,181.9	1,925	14,824.1
Atland Heavy Lift	5	14,255	2,851.0	1,560	4,474.0
Sankuy	2	40,460	20,230.0	0	9120
Cosco	2	26,462	13,231.0	0	6,762.0
West India Lines	2	1,846	923.0	0	797.9
Total	**78**	**793243**	**126617.8**	**28091**	**143886.8**

Table II: Overview of the heavy lift shipping companies, 1992

The major routes of the four companies do not differ much. They all work worldwide. The major route in the offshore segment is from Japan to the Far-East, followed by the route from Europe to the Far-East and from Europe to the Middle-East. The major routes for maritime infrastructure are the inter-European-routes and the route from Japan to the Far-East. The major routes for the industrial infrastructure are from Japan to the Far-East, followed by routes from Japan, Europe and North-America to developing industrial countries.

About 70% of all heavy lift transport is obtained on the spot market. These operations are based on single voyage contracts, which are agreements covering the transport of a specific cargo between specified ports for a fixed fee. The other 30% is obtained through consequtive voyage charters and time charters. A consecutive voyage charter is used when the terms of a single charter are extended for subsequent voyages, performed in direct continuation. A time charter is used when the operator hires the ship from the shipowner for a fixed period to be employed in his fleet.

6.2.3 Dutch competitiveness in heavy lift shipping

Firms, not nations, compete in international markets. It is necessary to understand how firms create and sustain competitive advantage in order to explain the role the nation plays in the process. Much is known about competitive advantage already. The question, however, is why a specific firm within a specific industry makes good choices instead of bad choices in seeking a basis for competitive advantage.

To determine the competitiveness of a nation's industry, several well-known methods for strategic analysis exist. The Dutch competitiveness in the heavy lift shipping will be determined using the analytical framework presented by M.E. Porter in *"The Competitive Advantage of Nations"*.

Porter's analytical framework consists of three major parts. The first part, the *Matrix approach*, determines the position of a nation's industry among other industries. The second part, Porter's *Diamond approach* determines the various attributes of a nation's competitive advantage. The third part, Porter's Five *Forces approach*, merely consists of a more detailed description of one of the Diamond's attributes: the competition and rivalry within a nation's industry.

The Matrix approach

The primary goal of Porter's Matrix approach is to determine and visualise the position of a nation's industry among other industries. With this knowledge, it may be possible to determine a firm's best generic strategy to fill a specific gap withing a specific industry, because these gaps and the respective generic strategies are readably visible after performing the Matrix analysis. Positioning within an industry embodies the firm's overall approach to competing within that industry.

The Matrix approach uses two axes to position an industry against another. The first axis, *competitive advantage*, is considered to play the most important role in the process of positioning. The second axis, *competitive scope*, is although less important, the other most obvious criterion for positioning.

Competitive advantage, once created and forcefully sustained, translates into a higher productivity than that of competitors, and therefore means success in the long run of a firm relative to its competitors. The basic types of competitive advantage are *lower cost* and *differentiation*. Lower cost is the ability of a firm to design, produce and market a comparable product or service more efficiently that its competitors. Differentiation is the ability to provide unique and superior value to the buyer in terms of product quality, special features or after-sale service.

Competitive scope is an indication of the breadth of the firm's target within the industry, concerning produced product varieties, employed distribution channels, served types of buyers and geographical areas, and related industries in which it decides to compete, too. Competitive scope is important, because it provides a firm with a given competitive advantage to choose a specific strategy to successfully compete with other firms in the industry or in neighbouring industries. It enables the firm to aim on a broad target or on a narrow target, whatever it prefers.

Together, the two axes of competitive advantage and competitive scope form four substantially generic strategies: differentiation, cost leadership, focused differentiation and cost focus. The meaning of these terms can be derived by determining their positions within **Figure 6**, which visualises the theory mentioned before.

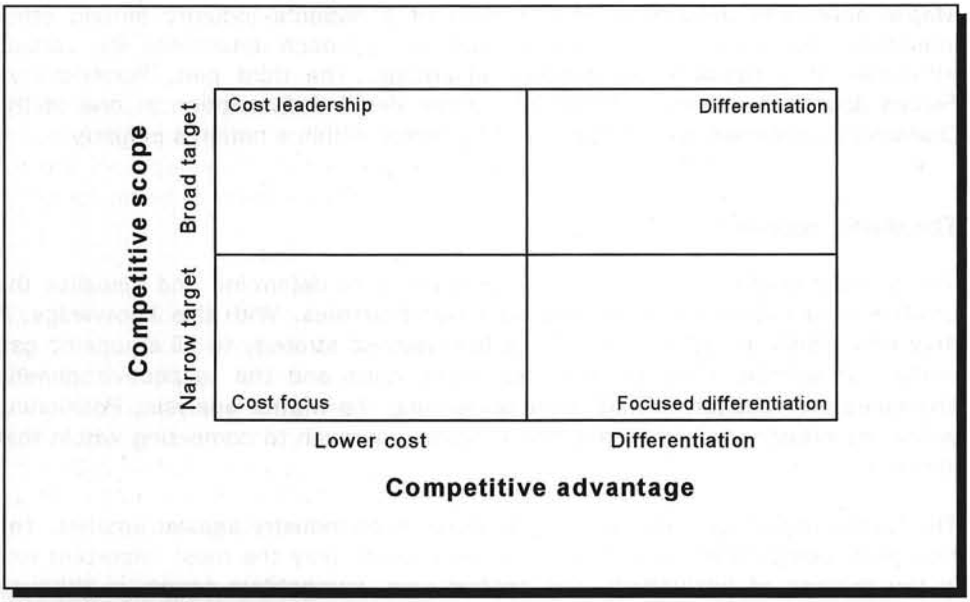


Figure 6: Generic strategies

Porter's Matrix approach seems to be appropriate to position the heavy lift shipping industry among other industries. Porter's entire vocabulary can be translated into shipping industry's terminology. The two axes of the shipping matrix can be described as *differentiation*, which replaces competitive advantage, and as *economies of scale*, which stands for the competitive scope.

Differentiation in ships, cargoes and trades of one shipping industry, can be described in terms of relative significance when comparing this industry to other shipping industries. Insignificant differentiation, which replaces Porter's lower cost, means that competitiveness can be earned or sustained by focusing the firm's generic strategy on lower cost. Significant differentiation, which replaces Porter's differentiation, means that competitiveness can be earned or sustained by focusing a firm's generic strategy on differentiation in ships, cargoes and trades.

Economies of scale in ships, cargoes and trades of one shipping industry can be described in terms of relative significance when comparing this industry with other shipping industries. Insignificant economies of scale, which replaces Porter's narrow target, means that competitiveness can be earned or sustained by focusing the firm's strategy on a narrow target in terms of the range of served economies of scale. Significant economies of scale, which replaces Porter's broad target, on the other hand means that competitiveness can be earned or sustained by focusing the firm's generic strategy on a broad target in terms of the range of economies of scale in ships, cargoes and trades.

Together, the two axes of differentiation and economies of scale, form four substantially different generic strategies, which can be described by using some well-known terminology of the shipping industry: *Industry shipping, contract shipping, specialty shipping* and *commodity shipping,* which respectively replace Porter's differentiation, cost leadership, focused differentiation and cost focus.

Differentation

Differentiation of ships is of apparent significance in the heavy lift shipping industry. Ships are especially built or transformed for one or few types of cargoes and/or trades, like transport of cranes or transport of yachts in between the Caribbean and Mediterranean. The resulting specialty shipping proves to be extremely competitive, because one company often is the only one who offers the required service. Also, new ships may create their own niches within the heavy lift shipping market, since cargoes may be adjusted to these new ships. For example, Dock Express' ships were especially configured to lift and transport large cranes.

Differentiation of cargoes is significant in the heavy lift shipping and directly inherent to the differentiation of ships. Extremely large and/or heavy objects are often very diverse and require subsequent diverse loading, unloading and transportation technologies and procedures. Only the industry shipping sector seems to offer less differentiated cargoes and trades, which slightly affects the significance of differentiation of the heavy lift shipping industry. Example: most of the heavy lift cargoes are exceptionally in weight, size and/or fragility, like rigs, barges, jackets, cranes, plants and even yachts, which require specialised handling and transport equipment and procedures, while some types of cargoes can be modulised, like industry and project cargo.

Differentiation of trades is normally insignificant, since there are no apparent differences or competitive advantages to be gained by operating different trading routes or contract within the heavy lift shipping industry.

The overall differentiation of the heavy lift shipping industry has certainly to be found within the specialty shipping region, where differentiation is of great significance. Only shipping operations for the industry and the trades turn the differentiation somewhat toward the commodity shipping region, where differentiation is of less significance.

Economies of scale

Economies of scale of trades is normally quite significant, since most operators can serve only few specific trades successfully. Often pools are formed to compete globally, spreading the interest over the various regions. For example: Dock Express' yacht transport services operate from the viewpoint of 'operational excellence', which ensures customers at least six trans-Atlantic trips per year at minimum costs and hassles.

The overall economies of scale of the heavy lift shipping industry has certainly to be found within the specialty shipping region, where economies of scale is of less significance. Only shipping operations for the industry and the trades turn the economies of scale somewhat toward the commodity shipping region, where economies of scale is of more significance. This result is in a direction of the heavy lift shipping industry which differs from the direction of other shipping industries: bottom-right to top-left instead of bottom-left to top-right.

A challenging position

Figure 7 visualises the position of the heavy lift shipping industry among other industries. It is obvious that the heavy lift shipping industry is found in an extraordinary situation among the other industries, both in the location and the direction of significance of differentiation and of economies of scale. Although it seems to be difficult to operate from such a kind of a non-conventional position, it enables operators within the heavy lift shipping industry to introduce and profit form subsequent non-conventional ideas. This, in turn, triggers new technologies, procedures and other activities, which makes the heavy lift shipping industry probably one of the most challenging shipping industries in terms of innovation and progress through the implementation of new idea. History has proven that Dutch operators were successful in this challenging position, and this, in turn, raises expectations for the future of the heavy lift shipping industry.

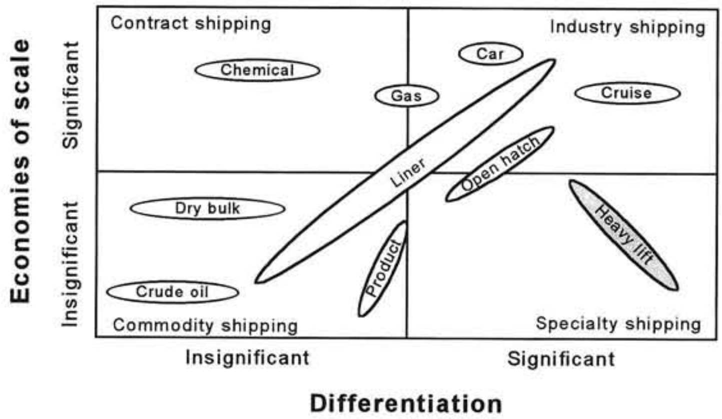


Figure 7: Shipping matrix

6.2.4 Competitive advantage

The competitive position of The Netherlands is analysed according to Porter's Diamond approach, the principle of the Diamond is already explained in section 5.5. An application of the Diamond has already been given in section 6.1.

The question that has to be answered is, why the Netherlands, compared to other nations, shapes an environment for innovation in the heavy lift shipping industry that moves faster and in the right direction.

Factor conditions

Historically, the Dutch have always had a special relation to the sea. The maritime sector has always been an important factor in the whole of Dutch industry. During the 1960s and 1970s the Dutch became important players in the tug/barge industry. From this moment on, they kept developing new ideas for transporting large structures all around the world, resulting in ships that are tailor-made for transport of heavy lift cargo. This brought a lot of knowledge about heavy lift shipping into the maritime sector. This knowledge is important and, if deployed efficiently and effectively, will result in higher-order competitive advantage. Research institutes such as the Institute for Perception in Soesterberg, the hydrodynamic research of MARIN in Wageningen, the research of Delft Hydraulics and Delft University of Technology have become well-known internationally.

The basic advantage of well-educated maritime officers has lost importance, mainly because the cost involved to man a ship with Dutch seamen is too high nowadays and the skills of cheaper foreign seamen have risen. This selective disadvantage is not an problem because it contributes best to the upgrading of the competitive advantage. The disadvantage sends the proper signal, which pressures the innovation (one-man bridge, remote control engine room).

The knowledge gathered with development of great maritime structures like the Delta works, canal, bridges, locks and dikes is also of major importance for heavy lift shipping. The selective disadvantages in geography became a stimulus for innovation and upgrading of the factor condition.

Demand conditions

According to Porter, the home demand is very important for industries to get a clearer or earlier picture of buyer's need than foreign rivals can have. The make-up of home demand determines how firms perceive, interpret and respond to buyer's needs. Pride and ego also focus attention on success in meeting demands of the home market. Finally, pressures from buyers to improve a product are most acutely felt in the home market, where proximity and cultural similarity make for clearer communications.

This is not true in the heavy lift shipping industry. In The Netherlands there is no home demand for heavylift shipping large enough to even make one company profitable. Heavy lift shipping is a typically international business in which countries have no real influence. Proximity of 'home demand' is found rather in the fact that in the early days heavy lift cargo was built in Europe and transported to elsewhere.

The presence of a great number of independent, influential buyers (oil companies like Shell, dredging companies like Boskalis) creates a good environment for innovation and investment. Because substitutes are always available (tug/barge, wet tow), competitors are pressured to reduce prices, introduce new features and improve products.

Related and supporting industries

Due to fierce competition of Asian shipyards in the building of relatively simple, large ships like oil tankers, the Dutch shipyards have differentiated towards the building of innovative, complex ships. Many heavy lift ships have been built at Dutch shipyards like YVC Capelle a/d IJssel (Jumbo Navigation) and Verolme Heusden (Dock Express Shipping).

There is a large maritime supporting network, which is internationally competitive like engineering & consultancy agencies, ship repair, technical firms, education, finance, classification societies and shipbrokers. The significance of related industries lies mainly in the ongoing coordination, the linkages between the value chains of firms and their suppliers which is important for development of new ideas and is a higher-order advantage.

Firm strategy, structure and rivalry

The organisation of a firm is a blue print of its goals. For the Dutch heavy lift shipping sector this means a flexible and small management with a focus on the long term future.

There is a willingness in the Dutch people to take risks, to travel, to learn new languages. Commitment and effort are of major importance in the heavy lift shipping. There is definitely an early movers advantage, the diamond structure with which competitive advantage is gained arose first in The Netherlands.

Rivalry among firms with the same home base is particularly beneficial for a variety of reasons. The four Dutch companies are an hour's drive away from each other. Such proximity accelerates diffusion of innovation, facilitates investment in skills, and encourages the development of supporting industries. It creates visible pressures on each other to improve in ways that upgrade the competitive advantages of a nation's firms.

Chance

Because the heavy lift shipping sector renders service towards the big oil/process/industry companies, it makes them very dependent on world business cycles. What counts are the companies that exploit these cycles best. The nation with the most favourable Diamond will be most likely to convert chance events into competitive advantages. But not only the Diamond is important; the Dutch companies Wijsmuller and Smit-Tak did not succeed in cooperating with each other during the Gulf-war, after which a third company got all the work.
It is important is to survive. The policy of cost reduction and non-investment does not trigger innovation.

Government

The maritime world is very much a free-market economy because of its great international character. That is why governments cannot control this market the way they do some other markets. They can and do actually influence the factor, related and supporting industries determinants. The Dutch government wants to influence the maritime sector because of the importance of The Netherlands as a maritime nation. The policy, as dictated in 'pushing toward the new century', is especially concerned with lowering tax-pressure and high exploitation costs, but Wijsmuller Transport, as well as Dock Express, have shifted their main offices to Belgium anyway. The Dutch government does not support the Dutch heavy lift shipping sector directly.

Internationally, governments promote the local building of factories, instead of construction somewhere else, and shipping it to its final destination. This reduces the opportunies for heavy lift shipping. Also the American Jones Act is not helping the creation of a large, free market.

The dynamics of the diamond

Even more important than having a Diamond is the change in the Diamond, and the pressures related to these changes. The whole dynamic system has to push companies to upgrade the factor conditions, to innovate. In The Netherlands the four heavy lift companies are competing with each other, so they will not fall asleep. That is important with a new competitor like SAL coming-up very strongly lately. The policy of waiting till the economy rises may not be the right one, but non-investment is understandable. The problem is that demand conditions are very strong, they have a lot of influence on the price. The costs involved in innovation normally does not result into higher revenues. Therefore there is no incentive and therefore other companies are threatening the Dutch hegemony. Attempts to work together instead of against each other have failed. Probably because clustering of the heavy lift sector will make them mutually supporting. It maintains diversity and overcomes the inward focus and magnifies and accelerates the process of factor creation. On the other hand, the idea of making a stand to the big companies to which they render their services, will be stopped immediately by the companies from other nations. The heavy lift shipping sector is just to international.

Porter's Five-Forces approach

The most complicated determinant of Porter's diamond is the firm strategy, structure and rivalry, which embodies the competition within an industry. Porter's Five Forces approach attempts to analyse and structure this dynamic determinant without inappropriate generalisations. The five forces are: the *internal rivalry among existing competitors*, the *external bargaining power of suppliers*, the *bargaining power of buyers,* the *threat of substitute products or services*, and the *threat of new entrants*.

Rivalry among existing competitors merely describes the rivalry among major competitors in the industry. Fierce competitive rival erodes profits by requiring higher costs in competing or by passing on profits by rivalry customers in the form of lower prices.
Bargaining power of suppliers exists due to the restricted number of suppliers of a product or service, and due to the level of risk of a firm's sales to any one supplier. Supplier forces can strongly alter and affect a firm's strategy, structure and competitive advantage among competitors.
Bargaining power of buyers, in a same way, exists due to the restricted number of buyers of a product or service and due to the level of risk of a firm's sales to

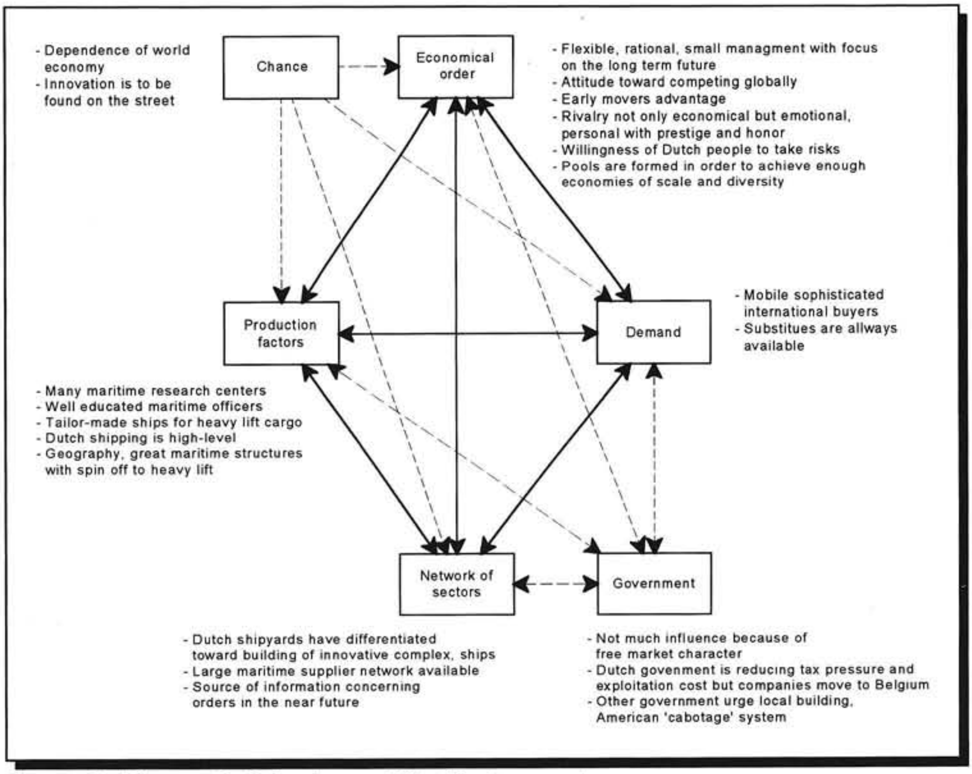


Figure 8: Diamond of the heavy lift shipping sector

any one buyer. Like supplier forces, buyer forces alter when the buyer can choose among a large number competing firms with comparable products or services.
Threat of substitute products or services is a special type of bargaining power of buyers, since in this case they can choose among several products and services of other firms when the number of substitutes is high and accessible. The presence of close substitute products limits the price competitors can charge without inducing substitution and eroding industry volume.
Threat of new entrants depends of the height of barriers for new firms to entry, such as extensive brand loyalty, highly-developed economies of scale, and the need to setup and penetrate distribution channels and a distribution network. Threat of new entrants limits the overall profit potential in the industry, because new entrants bring new capacity and seek market share, pushing down margins. Together the five-forces are visualised by **Figure 9**.

In industries in which the five forces are favourable and more or less equal, many competitors earn attractive returns on invested capital. Industries in which the pressure from one or more of the forces is significantly more intense then

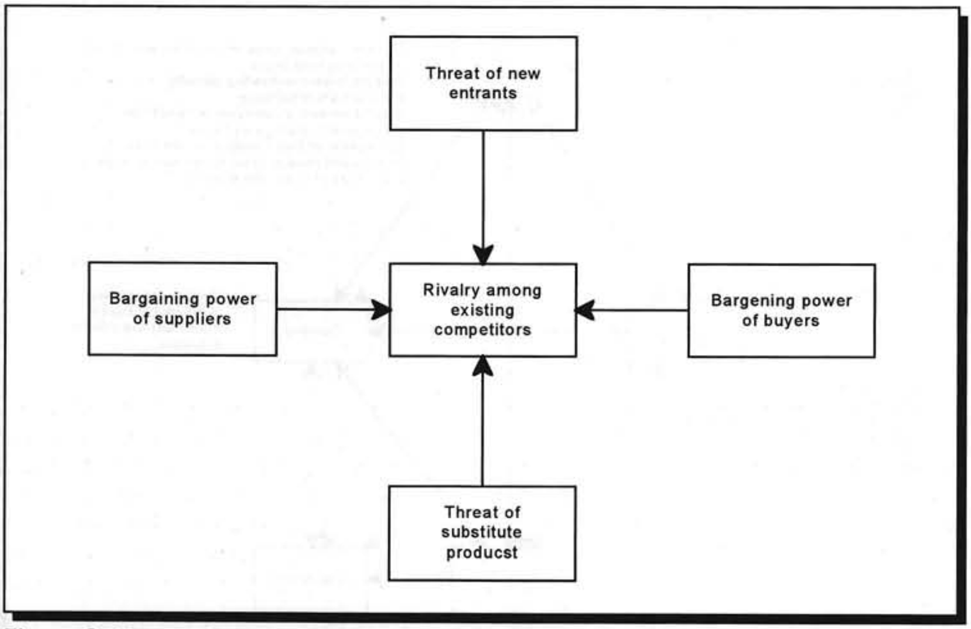


Figure 9: Determinants of industry competition

other forces, are ones where few firms are very profitable for long periods.

Rivalry among existing competitors

The four Dutch companies have a policy of consolidation, waiting until the economy picks-up, non-investment, cost competition (life time extension modernisation of ships instead of building new ones) and looking for ways to reduce the capacity in the sector. Competition is hard and not always rational for the outside observer. Attemps to cooperate have failed many times.

Bargaining power of suppliers

The bargaining power of suppliers who do the transport onshore is not big because of the domino-effect; the heavy lift shipping is very cost oriented, they look for the best bargain at the right price. This situation is not conducive to innovation within the maritime sector. The sector of maritime suppliers is very important for innovation but it is rewarded with higher revenue and company loyalty in the triangle of shipping company, shipyard and supplier. The power of insurance companies, agents and brokers is much bigger because the heavy lift companies need them to get orders and stay competitive with substitutes like the wet-tow or tub/barge.

Bargaining power of buyers

The buyers have a great bargaining power, because there is always the substitute of a wet-tow or tug/barge. They can pay minimal prices and still demand high quality. That is the reason why, in spite of the monopoly of Wijsmuller in transport of rigs by submersible ship and Dock Express in transport of fully erected cranes, they cannot set the price. Only when something special has to be transported, the rules change. Price sensitivity varies among the different segments of heavy lift shipping because of different rates in oil/process industry and insurance premium.

Threat of substitute products

Heavy lift shipping proceeded from the situation that wet-tow or tug/barge transport of heavy cargo became too expensive, especially because of insurance premiums. Nowadays these substitutes still exist and play a significant role in the price fixing capacity of the heavy lift shipping companies. The wet-tow and tug/barge are at the bottom of the heavy lift shipping market. The heavy lift shipping companies must continuously prove that their concept is the safest and most reliable way of transport of heavy cargo, better and more safe than transport in parts or construction on the spot.

Also multi-purpose ships like Seateam's product tanker/heavy lift ships depress the market. They sail around as product tankers when revenue in this sector is good, but within a day they can become heavy lift ships.

Threat of new entrants

Starting costs are high and market volume relatively low in the heavy lift shipping, but it is possible for people to get a foothold, if they know the shipping business and especially the financial world. A newcomer has the advantage of building new ships, which can perform better. Another way to start a company is, like the US Navy does, by building their own submersible heavy lift ships in spite of several attempts by Wijsmuller to offer a ship guarantee program. These ships will compete in international shipping, when not needed by the US Navy, and Wijsmuller will lose some good trips they had during the Gulf war. Another threat is heavy lift ships from Russia. By taking these ships under their management the Dutch companies have control, for the time being.

Competition is mainly focused on cost, quality, expertise and know-how. Features which are not often found amongst newcomers.

A competitive industry

Competitive strategy must grow out of a sophisticated understanding of the structure of the industry and how it is changing. The nature of competition is embodied in the five competitive forces named above. Because of the decline of world economy, the heavy lift sector is faced with too much capacity. The Dutch companies try to get a hold on this problem. The cost focus is not stimulating technological innovation. Market innovation and cargo handling are the ways in which the companies try to stay competitive without big investments. Innovation, early adopters of innovations are the strong side of the Dutch heavy lift shipping companies and to safeguard this for the future a policy of aggressive investment and cooperation with related industries are needed.

6.2.5 Conclusion

The Netherlands are very strong in the heavy lift sector. They own more than fifty percent of the entire world fleet capacity. Because of the overcapacity in the sector, the Dutch shipowners invest very little in new ships but put a lot of effort in life extension programs of their existing ships. This may give them a disadvantage in comparison to other shipowners who do invest in new ship.
The position of the Dutch heavy lift sector has always been and still is strong. In the Netherlands is a lot of expertise and the competitive position is still favourable. But competition is strong and the Dutch shipowners have to remain very alert to maintain their competitive lead.

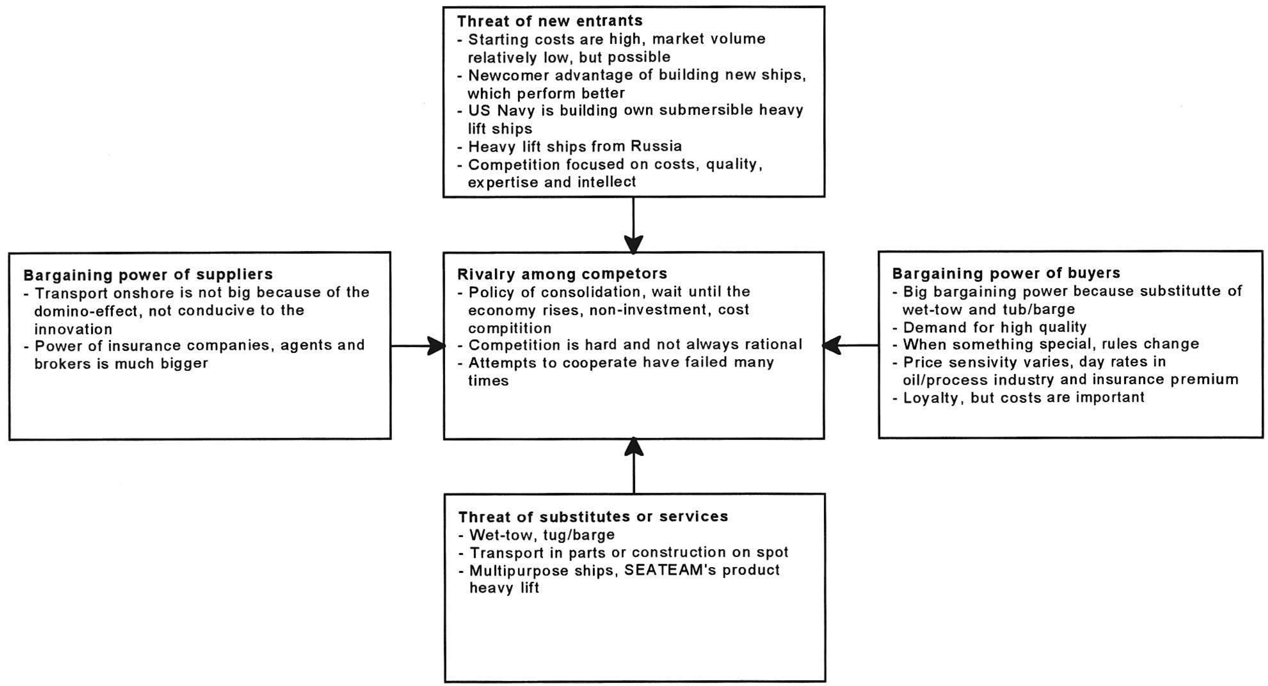


Figure 10: Competitive advantage of the Dutch heavy lift shipping sector

6.3 Chemicals shipping in Norway

In 1992, the Centre for International Economics and Shipping examined the Norwegian shipping sector on the basis of Porter's methodology. Nine segments were analysed and reports published. These segments are tanker, dry bulk, open hatch, cruise, gas, oil products, chemical and liner shipping. This section highlights the main findings of one of the segments in which the Norwegians have been particularly innovative: chemicals shipping.

6.3.1 The chemical shipping market

In the broadest sence a chemical tanker can be defined as a *technically advanced ship, able to carry a range of petrochemicals and non-petroleum liquid cargoes*. The cargoes carried can be split into four distinct market sectors:

- Organic chemicals;
- Inorganic chemicals;
- vegetable/animal oil and fats;
- Molasses.

Each of the products carried in bulk in chemical tankers requires carefull consideration as to their compatibility with other cargoes carried and with the various tank coatings, method of containment, heating requirements, pumping arrangements, tank cleaning procedures, etc. I.M.O. has divided the cargoes and the chemical tankers into three categories, Type I, Type II and Type III, of which type I cargoes are most hazardous.

Chemical tankers are constructed from either mild steel or stainless steel. Mild steel is almost always coated with a protective covering to protect both the cargo and the tank. Stainless steel tanks are more expensive but have a better quality.

The chemical fleet can be divided into several groups and subgroups:

- General chemical tankers:
  - Parcel chemical tankers;
  - Simple chemical tankers;
  - Dedicated single cargo tankers.
- Chemical/products tankers;
- LPG/Chemical tankers.

General chemical tankers
Parcel tankers are designed to carry a number of chemicals in small lots, usually on a worldwide liner type service on established routes. The ships are characterised by a large number of tanks, up to 58, and a seperate pump and load/discharge line for almost every tank. The tanks are a mix of stainless steel and mild steel with various coatings.

Simple tankers have a less sophisticated cargo handling system and can accomodate fewer products. The simple chemical tankers are suited to ship larger parcels of commodity chemicals, like caustic soda, phosphoric acid and methanol mixed with e.g. vegetable oils, animal fats and molasses.

Dedicated single cargo tankers are built to transport specific commodities, like phosphoric acid, methanol of fuel additive.

Chemical/products tankers
There is an overlap between chemical tankers and the refined petroleum products carriers. The advanced products tankers usualy have an I.M.O. certification of II. The most important difference between parcel tankers and the product tankers, is that the product tanker does not have any stainless steel tanks, nor is it able to carry as many types of cargo.

LPG/Chemical carriers
These vessels are capable of transporting both LPG gas and chemicals, though the ability of these ships to carry hiavier chemicals is limited as the vessels are primarily designed fo r carrying light gasses.

LPG/chemical tanker fleet make-up less than 2% of the entire chemical tanker fleet. The rest is divided equaly between general chemical tankers and chemical/products tankers.

The most distinctive feature of the seaborne trade of chemicals is the diversity of cargo ships and ship categories. The wide range of ship types, the complicated trading patterns and the variety of cargoes, all results in a very complex market segment. This study mainly focusses on the parcel chemical tanker market for vessels above 10,000 dwt. used in the deepsea trade. **Table III** gives an overview of the entire chemical tanker fleet as per end of June 1991. 15.7% of the fleet's tonnage is registered in Norway. Flags of convenience, like Liberia and Panama, account for respectively 19.9% and 13.4%.

At the beginning of 1991 the major operators in the market were JO Tankers (Norway), Odfjell Tankers (Norway), Stolt Tankers & Terminals (U.S.A.) and Seachem Tankers (U.K.). The fleet shares of each of the operators is shown in **Figure 11** (for vessels above 10,000 dwt). It shows that 74% of the dwt. of the chemical carrier fleet is operated by these four shipowners.

DWT	Chemical		Oil/Chemical		LPG/Chemical		Total	
	No.	Dwt.	No	Dwt.	No.	Dwt.	No.	Dwt.
5,000-9,999	296	2087	25	194	9	72	330	2352
10,000-14,999	67	8313	29	375	11	139	107	1327
15,000-19,999	43	743	27	485	4	73	74	1301
20,000-24,999	27	632	35	805			62	1437
25,000-29,999	37	1016	34	972			71	1988
30,000-34,999	41	1331	23	739			64	2070
35,000-39,999	20	747	32	1239			52	1986
40,000+	5	279	54	2774			59	3053
Total	**536**	**7648**	**259**	**7583**	**24**	**283**	**819**	**15514**
% of tal	**65**	**49**	**32**	**49**	**3**	**2**	**100**	**100**

Dwt in 1,000 tonne

Table III: Overview of the chemical tanker fleet

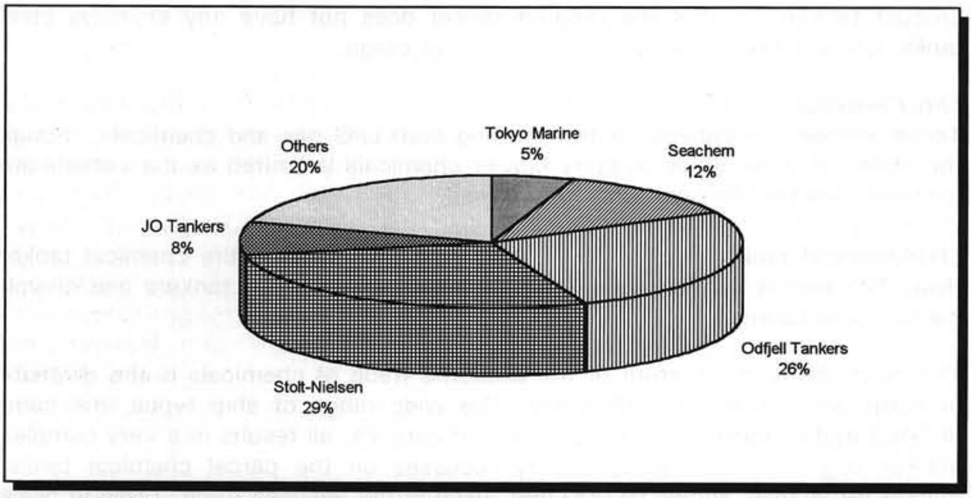


Figure 11: Shares of the chemical tanker operators

All of these operators have links to Norwegian shipping. JO Tankers and Odfjell Tankers are both situated in Bergen. Together their market share is 34.5%. The owner of Stolt Tankers & Terminals is an emigrated Norwegian, with considerable connection with the Norwegian maritime environment. Seacham Tankers is a pool between several shipowners, which comprised Fearnley & Eger (which went bankrupt in 1991).

6.3.2 The Norwegian competitive position

The matrix approach

The matrix approach has been explained in section 6.2. This section places the chemical tanker market into the matrix.

Differentiation

the chemical tankers as a whole, are differentiated with a range of vessels from advanced, flexible ships to simple, dedicated ships. Given the large number of cargoes and the various requirements related to each chemical transported there is room for differentiation.

The shipowner has the choice to specialise in simpler or more advanced ships, shortsea or deepsee transportation and between a range of vessel sizes. There can be a large variety of different vessels within a fleet, though sufficient capacity for each type is required.

Economies of scale

The customers of chemical tankers services are mainly big companies in the petrochemical or other chemical industries, who demand an extensive transportation service. The customers require regular services, which makes this business very similar to liner shipping, although there are no conferences. Small part loads from several customers to many ports require regular sailings, heavy marketing and a large fleet that is able to operate worldwide.
A contract will require a minimum number of vessels as to cover the regular sailings. To be able to offer these services within deepsea trade worldwide, a certain size of fleet is required, which requires economy of scale. However, the economies of scale do no exclude the possibility of operating profitably within a niche of the chemical carrier market or letting one of the major operators time charter smaller fleets.

The chemical tankers as strategic market type

Next to the high investment costs due to the specialised, expensive vessels, fixed costs are considerable, when operating worldwide. At the same time a certain fleet size is required to be able to compete in this market, as the economies of scale aspect is significant. Differentiation implies offering different services. Although there are many types of products requiring different cargo handling, most operators' fleets are able to transport the bulk of these products. Only dedicated vessels like acid carriers can offer services for one product only.

Thus in the chemical tanker business, there are elements of differentiation, but these are not considered to be significant. **Figure 12** shows the shipping matrix for chemical shipping.

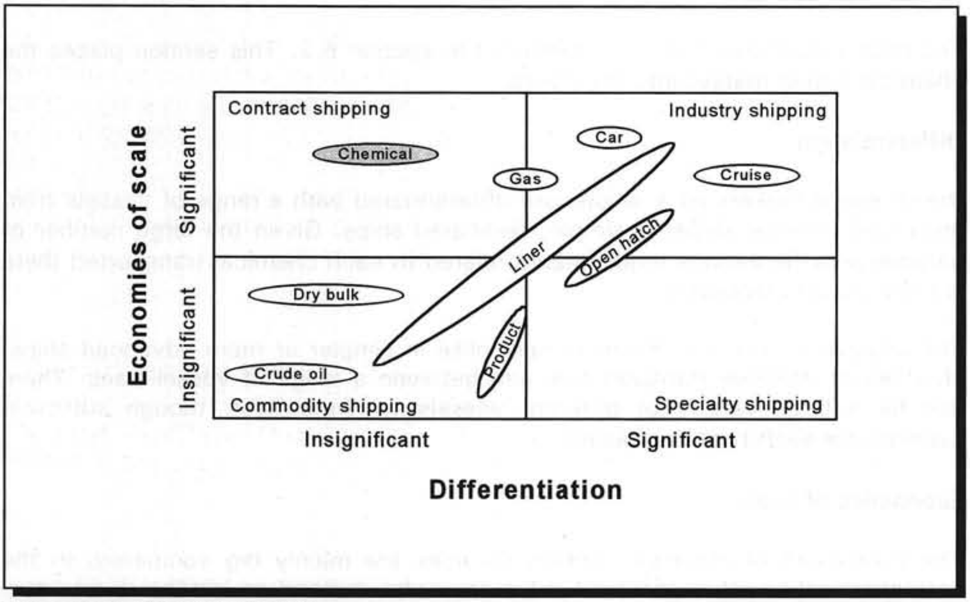


Figure 12: Shipping matrix

Competitive advantage

The competitive position of Norway is analysed according to Porter's Diamond approach, of which the principles have already been described before.

Factor conditions

At the centre of the traditional theory of international comparative advantage lies the factor of production. None of the 'basic' factors such as natural resources, climate, location and demographic, play an important role for sustaining the competitive advantage for Norwegian chemical tankers operator.

Product tankers played an important role in the pioneering phase of the seaborne chemical trade. Norway had a significant part of the world's fleet of tankers then, and the vessels were mainly crewed by Norwegians. Cargo handling expertise is essential. Because Norwegian seamen were well qualified, this was an advantageous factor condition.

Today the situation is different. Norwegian seamen are so expensive that none of the operators who compete in international shipping, can afford to keep a full Norwegian or European crew. No Norwegians are working on the lower levels. If the nation wants to stay in the lead when it comes to seamanship, recruitment is vital.

The operators always had an extensive knowledge of bulk liquid cargo handling and the shipping markets. The Norwegians who did start the chemical trade were all already involved in shipping. During the years the operators have created a factor condition in Norway, human knowledge.
The technological base, which already existed in the shipyards, in the shipowning companies and the suppliers of equipment was a favourable factor condition for further development of chemical tankers.

Demand conditions

The demand for seaborne chemical transportation is of course closely related to the development of the petrochemical industry, other chemical industry and the current crop of vegetable oils and molasses. The direct relationship to hydrocarbons, particularly crude oil, links the petrochemical industry to the petroleum industry.

Norwegian companies are no major customers of, nor producers for, overseas chemical transportation. The operators have managed to be players in an international market, and keep close customer relations all over the world.
The main customers of the deepsea trade services are big multinationals situated in the U.S.A., in the Arab countries, in western Europe and in South America. Trade patterns have changed significantly over the years, but from the very beginning, companies situated in the U.S.A. have played a major role in the market.

The American companies produce primarily for the home market. Depending on the home demand the exports have fluctuated through the years. Even though the customers of chemical shipping services are mostly huge in comparison to the shipowners, their overseas shipment volumes do not justify the building up of their own fleet of chemical carriers considering the services that exist. To operate a fleet they would be dependent on operating in the market, moving into the transport services trade, which apparently is not in their interest. This accounts for overseas transport. The picture for interregional transport is different. Some industry companies have moved into seaborne transportation but with no success.

The multinationals are demanding customers to serve. Today, only small stocks are kept at the plant sites, as regular sailing by chemical tankers to different ports around the world are relied upon. The customers are dependent on service reliability, which includes such aspects as vessel arriving in time, cargo delivered in time, no losses of cargo, no contamination and no pollution spills. Today these aspects are important in negotiations for a contract, whereas earlier the customer seemed to care primarily about gaining the lowest possible rate. The operators are recognised as experienced specialists, essential for the transport of liquid chemicals.

The chemical companies have not been primarily interested in the safe transportation of their products, but rather regarded it as non of their business. In this sense the shipowners have been left to themselves to solve the problems involved in carrying chemicals. Today, this is changing and the chemical companies have been forced to be more concerned over the delivery of their cargoes.

Related industries

Shipyards

Traditionally the European, especially the Scandinavian shipyards, have been the principle builders of chemical tankers. By the 1970s, emerging shipbuilding countries like South-Korea and Poland were able to build sophisticated vessels at competitive rates. Despite this, a large part was still built in Norway.

The yards were extensively used by Norwegian operators as good contacts had been established and the costs were not too expensive in comparison to lowcost shipbuilding countries such as South-Korea. Factors favourable were, for instance, no political risk, secured delivery and no communications problems. Apparently these advantages are not attractive enough any more, as increasingly Norwegian shipowners started to build abroad. Now, only one shipyard remains building advanced chemical tankers above 10,000 dwt.

There seems to be an unspoken consent among the major shipowners not to distribute the achieved technical knowledge easily to other potential competitors. When the major operators build series of vessels at relatively small Norwegian shipyards, the capacity and the connected skills are occupied, and other competitors are excluded from ordering for a few years. The entry barriers are thus reinforced. On the other hand it might turn out to be a disadvantage that the building experience is kept in Norway, as there will be few serious potential builders next time around.

Sub-contractors of equipment

Norwegian shipyards and shipowners are granted support from the governments as long as they do not purchase more than 25% of the vessel's value from foreign sub-contractors. The shipowner is entitled to an ordering grant of 10% whereas the shipyard gets 1.45%.

Many sub-contractor of the yards are located close to the shipbuilding areas and have strong relationships with both the yards and the shipowners. Continued cooperation between the shipowner and the sub-suppliers, even at times with no newbuildings is not considered unusual. Often, the shipowner supplies the shipyard with a 'makers list', listing his choice of possible suppliers. The shipyard is then free to choose one of them.

Shipbrokers
Shipbrokers, in Norway, who are more or less specialised in chemicals/products trade are often former exployees of one of the major shipowners. These shipbrokers are primarily used by the smaller chemical tanker operators for fixing cargoes and for matching time-charter partners.

The operators have built up their own 'in-house-shipbroking', which they use for the fixing of cargoes. This can partly be traced to the times when the chemicals trade started as something new. The operators had to do active marketing themselves, as it could not be expected that the established shipbrokers had enough knowledge to take care of this business in a proper way. In addition, the chemicals trade was not very attractive for the shipbrokers. The work involved with shipments is very much the same, no matter what the volumes sent are, whereas the payment is a percentage of the cargo's value. As the volumes and the lots of chemicals were small, the shipbrokers were not very interested.

Bank/financial institutions
Some of the Norwegian banks have acquired considerable experience in shipping finance as the 'home base' banks for Norwegian shipowners. The banks have knowledge of the markets and they have been willing to take part in projects.

Classification
Det Norske Veritas is one of the worlds well-recognised classification societies. The interrelations between the class societies, the shipowners, the shipyards and the sub-suppliers are many.

External influences

International regulations
The I.M.O. Code was formally adopted by the I.M.C.O. Assembly on 12th October 1971, and on 12th April 1972 it became applicable to all ships under construction or conversion. In 1978 the Code was applied to all ships built before 1972. This resulted in older converted product tankers being taken off the chemical trade. Both Stolt-Nielsen and Odfjell-Rederi/Westfal-Larsen had anticipated this development and had ordered ships, in the beginning of the 1970s, that met with the new regulations. This 1973 Pollution Convention (MARPOL) was revived and reinforce in 1978, which can be seen as a continuation of the strengthening of the requirements for transport of liquid bulk cargoes of dangerous chemicals.

Generally, the shipowners played a proactive role in the 1960s and the 1970s. The customers did not care about the vessels as long as the transportation was cheap, the international bodies dit not know what the chemicals trade was all about, the environmentalists were still a small unknown group and the only ones recognising the problems were the shipowners themselves. There was a lot of trying and failing, without anyone knowing the consequences. The 1980 were marked by the implementation of the rules and the overseeing by bureaucrats in the organisations. The impact of international and local regulations meant that serious operators, with specialised skills in dangerous chemicals and an up to date, good quality fleet have turned out to be the winners of the market.

Chance
Entrepreneurship, after the end of the Second World War, two main factors lead to the rise of a completely new type of ship:

- The simple increase in volume in chemicals output and trade justified the shipment in bulk;
- The increase in the variety and sophistication of hazardous chemicals brought about the need for strict segregation of a large number of cargoes in one vessel.

In the late 1950s Jacob Stolt-Nielsen Jr., living in the U.S.A., was one of the first to recognise the emerging demand for bulk shipments of specialty liquids. The Odfjell Rederi was originally involved in dry bulk cargoes. The family owned shipping company was visionary in that they had a vessel with stainless steel capacity built as early as 1960.

Economic order

The economic order is analysed according to Porter's Five Forces approach for the firm strategy, structure and rivalry, explained in section 6.2. The Five Forces approach consists of the following five factors:

- Potential entrants;
- Buyers;
- Substitutes;
- Suppliers;
- Competition.

Potential entrants
High returns on investment will always attract newcomers. After the peak at the beginning of the 1980s, the rates decreased and stabilised at a low level, which apparently did not justify investments by new entrants. Still the Japanese entered with their series of 8,000-12,000 dwt. chemical tankers and squeezed the market even more. No other major competitor appeared in the market during this period. High barriers of entry exist for several reasons:

- Chemical tankers are very expensive in comparison to other, simpler vessels;
- Secondhand market is very small, close to nonexistent, newbuildings are necessary;
- Operations of the ships require skills that are developed through experiences; the experience must be obtained from some of the existent operators and this adds to the investment costs;
- To be able to serve the petrochemical plants a minimum sized fleet combined with the provision of certain necessary services is essential;
- Extensive marketing expertise is needed to ensure high fleet utilisaiton;
- Relations between the existing operators and the customers are strong; they are difficult and time-consuming to obtain.

In the spring of 1990 a new company with well-founded knowledge of chemical tankers operations, was established by previous employees from the major operators, Storli and Stolt Tankers & Terminals. The company was called Chemteam. One of the company's goals in the future was to be able to compete with the big operators. Vessels were hired from chemical tanker owners on 3-12 months basis and operated by Chemteam. At the time when Chemteam started, freight rates were expected to rise significantly. After a year of operations, the Kuwait crisis ended and rates fell below what the vessels had been contracted for. In autumn 1991 it was decided that the company would withdraw from their activities. All equity capital was lost.
Even though the vessels were operated with a surplus in the beginning, capital required to survive times with lower freight rates was not available, and the investors were not willing to continue their support.

Buyers
The large multinationals who are the buyers of the transportation services, posses a lot of power. Up until today the overseas export share of the producers total volume has not been large enough for them to consider getting engaged in the seaborne transportation service. This is changing since the Arabian countries have started producing specifically for export and are investing in big plants in Arabia. The U.S.A. has also become more aware of their export business.

Substitutes
A possible substitute is the substitue of the products carried by chemical tankers and their production and consuming areas. In the forecast demand for chemicals, growth is expected in all groups. Methanol is expected to grow at a high rate at the same time as tetralead will decrease in trade as it is generally accepted that less lead should be consumed an other less dangerous products to the environment should be used.

Other substitute threats are new production facilities closer to consuming areas and a less balancing trade between the continents. Trade patters change constantly and the changes are followed closely by the participants in the market.

Plants producing one or only a few grades of chemicals enable the use of dedicated tankers. The ability to carry a multiplicity of parcels will not be needed and a product tanker can be used without having to pick up backhaul cargoes in order to be economic.
Product tankers may develop into more advanced ships, which are possible substitutes. As product tankers are able to carry more demanding product, the sophisticated chemical tankers could be left with a very small market for special trades. Today product tanker are regarded as substitutes for the major operators only as part of a mixed fleet.

Suppliers
In shipping, suppliers cannot be understood in the same sense as in manufacturing. In the chemical tanker market, the suppliers are the shipbuilding industry, shipbrokers, financial institutions, insurance companies and classification societies. Some of these suppliers have been seen to be playing an increasingly important role. Insurance has increased significantly and at the same time classification has become harder to obtain.

Competition
The chemical tanker market (vessels above 10,000 dwt) is a specialist niche market with few major competitors, operation in an environment as described above. Other features that characterise the chemical tanker business are as follows:

Rivalry
A strong force in sustaining competitive advantage is rivalry. In the late 1950s and the beginning of the 1960s, the Bergen based shipowners entered the new chemical trade. The fact that Odfjell, Westfal-Larsen, Mowinckels, Team Tankers, all situated in Bergen, went into the chemical trade, whereas only a few smaller shipping companies from other parts of the country did so, can be considered as a clear indication of contacts/cooperation and rivalry of this special environment in Bergen. During the years, changes have taken place as to ownership interests, cooperation operations of vessels, but as of today only two of the world major operators are still situated in Bergen, Odfjell Tankers and JO Tankers.

Cooperation
The operators do not necessarily own their vessels, but may charter them on a time charter basis from the shipowners, or they join in pools with other operators. This has obvious advantages for both sides. The operator is able to cut back on capital investment, while he still has access to the tonnage that may be required. On the other hand, owners are able to benefit from the experience that the operator has gained during years of service and they thereby obtain the need to operate the vessels themselves. Often there is an option attached to the deal enabling the operator to buy the vessel at the end of the time charter period.

Officially no cooperation exists among the operators. However, there seems to be a collective market perception about the advantage of having few operators in the market. Their newbuilding programmes also give the impression that the fleets are somehow kept in balance.

Strategy

Essential in this industry is to keep the fleet up to date. The major Norwegian operators update their fleets constantly to meet the international regulations of tomorrow. Historically the fleet has always been relatively modern. Chemical tankers are considered to be ready for scrapping or another trade after the age of 20, at least this is the general opinion for vessels built before 1975. Considering the aging fleet, there is room for newbuildings. If the vessels can be run safely and securely until they pass twenty-five or even thirty years, the picture will be different.

Porters diamond for the factors for sustaining competitive advantage is shown in **Figure 13**.

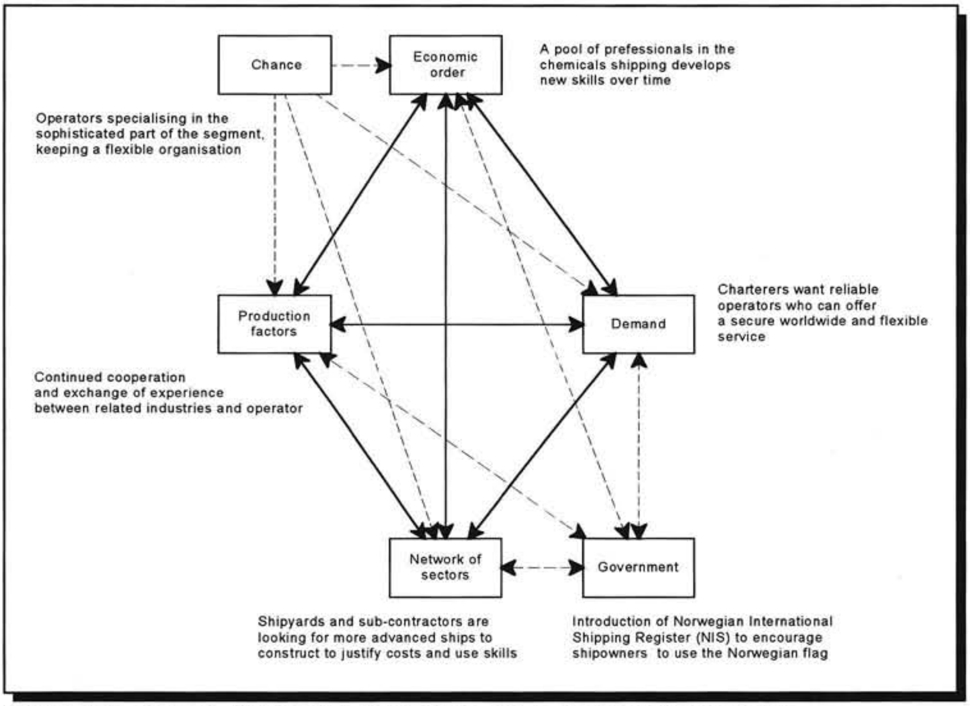


Figure 13: Porters diamond for the Norwegian competitive position

CHAPTER 7: S-CURVES AND INNOVATION IN SHIPPING

In the previous Chapters, the relationship between innovation and the economy has been discussed and a number of concepts have been presented from different perspectives. In this chapter, two innovation concepts will be added: the S-curve and Benchmarking. The originator of the S-curve model is probably E.M. Rogers, but the concept got widely publicised through a book by R.N. Foster titled, *"Innovation: The Attacker's Advantage"*. The benchmarking concept is a logical extension of the S-curve, as it is a method of defining performance indicators and its measurement.

7.1 The S-curve

Figure 1 shows the S-curve graph. This is a relationship between the effort put into improving a product or process and the results one gets back for that investment. It is called the S-curve, because when the results are plotted a sinuous line shaped like an S appears, but pulled to the right at the top and to the left at the bottom.

Initially, as funds are put into developing a new product or process, progress is very slow. Then, suddenly, as key knowledge necessary to make advances is developed, the performance starts to increase rapidly. Finally, as more effort (manpower, investment) is put into the development of the product or process, it becomes more and more difficult and expensive to make technological progress. And that is because of (invisible) limits at the top of the S-curve.
In the business world, limits determine which technologies, which machines or which processes are about to become obsolete. They are the reason why products eventually stop being competitive and will disappear. They have reached the ultimate stage of the product life cycle. So the limits of the S-curve are linked to the decline phase on the life cycle. The life cycle has time on the horizontal axis and sales volume on the vertical axis. Although it shows similarities with the S-curve, it represents quite a different concept.

In order to surpass the limit of a certain technology, it is often necessary to adopt a completely new technology. This will create a discontinuity in the S-curve; actually, it will start a whole new S-curve (**Figure 2**). Foster's book provides many illustrations of S-curve shifts. For example the switch from vacuum tubes to semiconductors, the switch from propeller-driven planes to jet propulsion, the switch from natural to synthetic detergents or fibers, the switch from records and tapes to compact discs. These are all technological discontinuities and they altered the pecking order in the various industries.

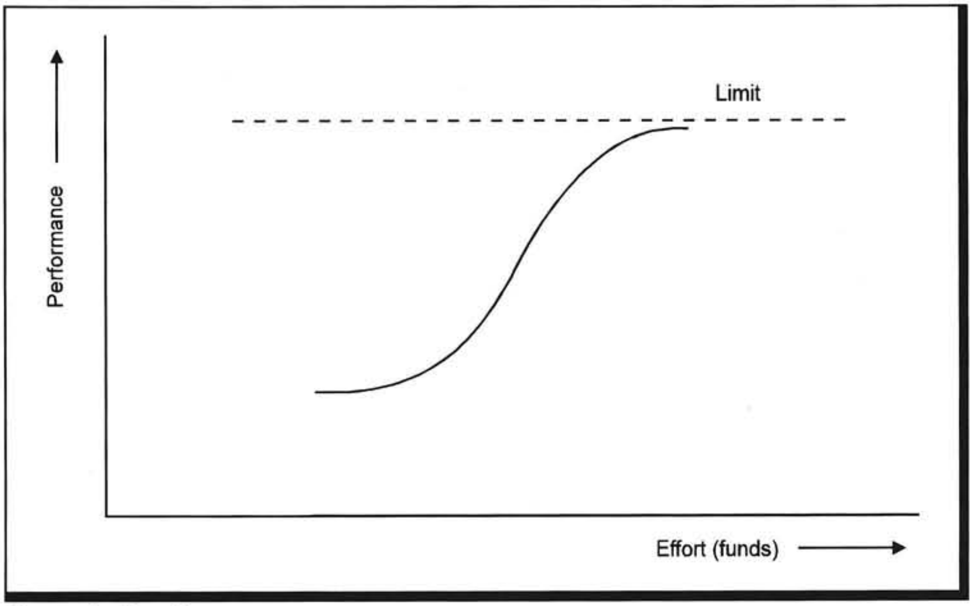


Figure 1: The S-curve

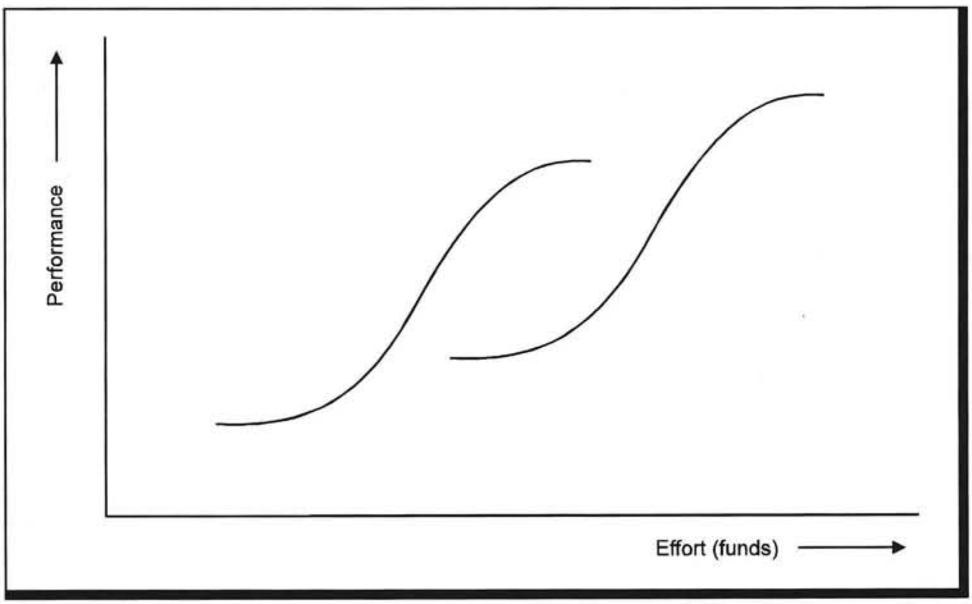


Figure 2: S-curve shift

One of the reasons why Foster subtitles his book *"Innovation: The Attacker's Advantage"*, is that defenders of an old technology are faced with increasing

R&D cost in order to achieve performance improvement: it becomes increasingly expensive to make progress. At the same time, the possibility of new approaches often emerges - new possibilities that frequently depend on skills not well developed in the leader companies.
The S-curve is not a new theory, but rather a new way of looking at innovation and technological change. It is a new paradigm, a term that will be discussed in **Chapter 10**.

7.2 S-curves and life cycles in the maritime industry

It is often difficult to reconstruct the S-curve of specific technologies as the information has never been systematically recorded or simply was never measured anyway. Therefore, it is often useful to take the product life cycle as a sort of substitute, as is the case in the following example on ship propulsion.

Historical development of power installed per ship's propeller up to 1990

Research by Prof. L. van Gunsteren in *"Management of Industrial R&D"* was directed to define the limits of the installed power per propeller on ships, see **Table I**. The definition of the technological limits was not only important to propeller manufacturers, but equally to engine makers, gear manufacturers and shipbuilders. He started his work from the assumption that cavitation and related cavitation erosion, would be the physical constraint (limit). Until 1972, the power per propeller had shown an exponential increase (**Figure 3**). The results of the research indicated that the turning point of the S-curve was approximately reached, in other words that the current trend would not continue but flatten off. This conclusion was based on the physical constraints of cavitation and extensive calculations with advanced computer programmes.

Propeller type	Predicted maximum power	Speed
Controllable pitch (CPP)	70,000 BHP	35 knots
Fixed pitch (FPP)	100,000 BHP	39 knots
Counter rotating (CRP)	150,000 BHP	45 knots

Table I: Prediction in 1972 of limits to power installed per propeller

Indeed, during the the decades following 1972, the realised power per shaft for fixed pitch and controllable pitch propellers grew close to the predicted limits (fixed pitch: almost 100,000 HP/propeller; controllable pitch: 60,000

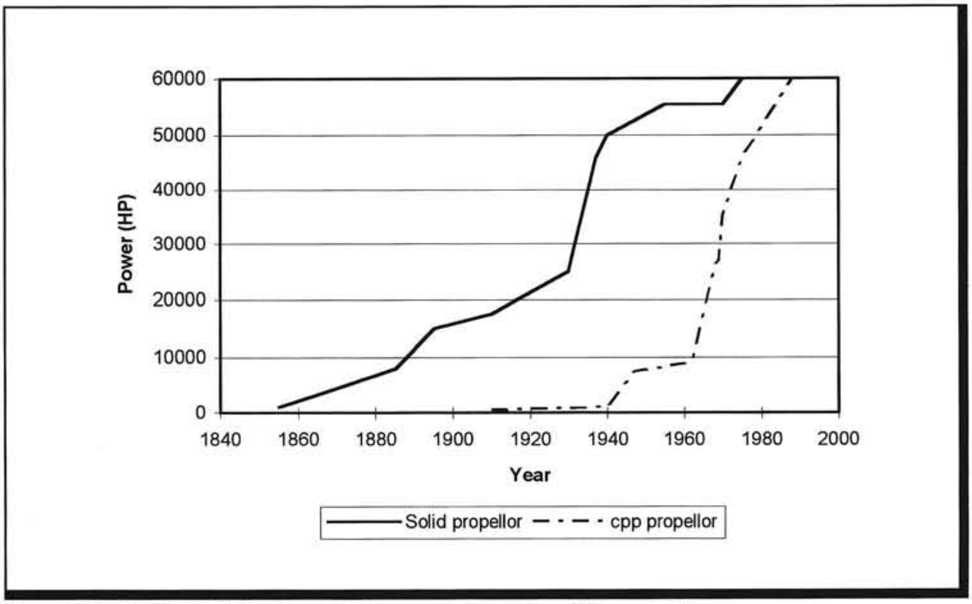


Figure 3: Limits of the installed power per propeller on ships

HP/propeller) but did not exceed them. In order to surpass these limits, a new class of propellers had to be developed, those of the super-cavitating propellers.

Diesel engines and gas turbines

The development of the installed power per propeller is closely related to the development of diesel engines. The performance increase over a twenty year period is clearly visible in **Figure 4**. The performance increase has many dimensions, of which horsepower per cylinder and the specific fuel oil consumption are most relevant.
When these performance graphs are related to R&D effort, then the resulting curve will resemble the S-curve. A further increase in performance will require even more funds, or a complete new technology, like the introduction of ceramics.

Figure 5 and **Figure 6** show the performance development over time of the gas turbine, related to the use of conventional alloys, super-alloys, and ceramics. This clearly illustrates that a performance increase of the gas turbine requires higher combustion temperatures that in turn can only be achieved by using ceramics instead of metal alloys.

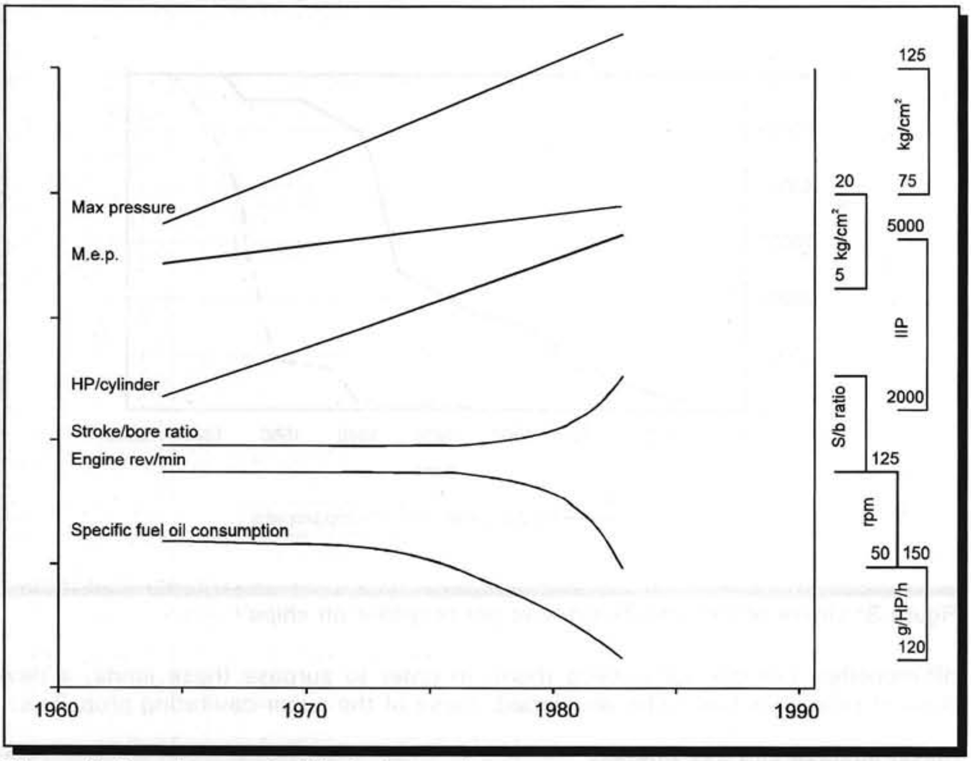


Figure 4: Development of 2-stroke engines

Marine propulsion for high-speed light craft (HSLC)

The comparison of high speed propulsion systems provides an interesting example of the performance indicators that are relevant in the S-curves. The comparison is made for a gas turbine and a diesel engine. The key technical performance indicators are shown in **Table II**. There are striking differences, such as the specific weight in kg/kW. The gas turbine needs only 0.6 kg. to generate 1 kW., while the diesel engine needs 2.5 kg. of weight to do the same. As engine weight is a crucial factor on HSLC, the diesel engine manufacturers are vigorously researching further improvement of this ratio. The HSLC engine operating costs comparisons **(Table III)** are based on a number of assumptions that may change from case to case.
This example makes it clear that R&D of engine builders will be directed towards the relative improvement of these performance indicators. They give direction and meaning to innovation in design and operation.

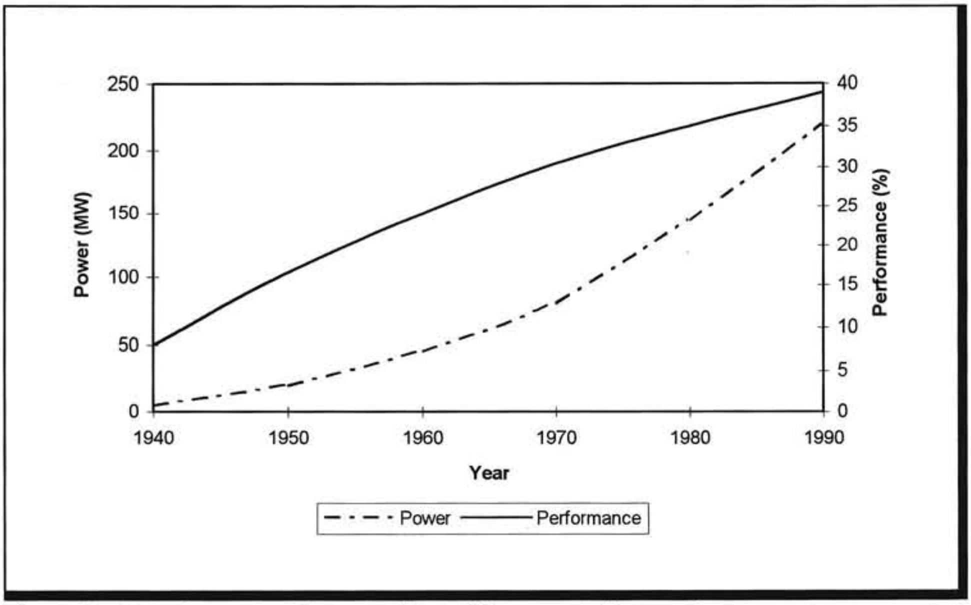


Figure 5: Development of gas turbines (1), gas turbine performance

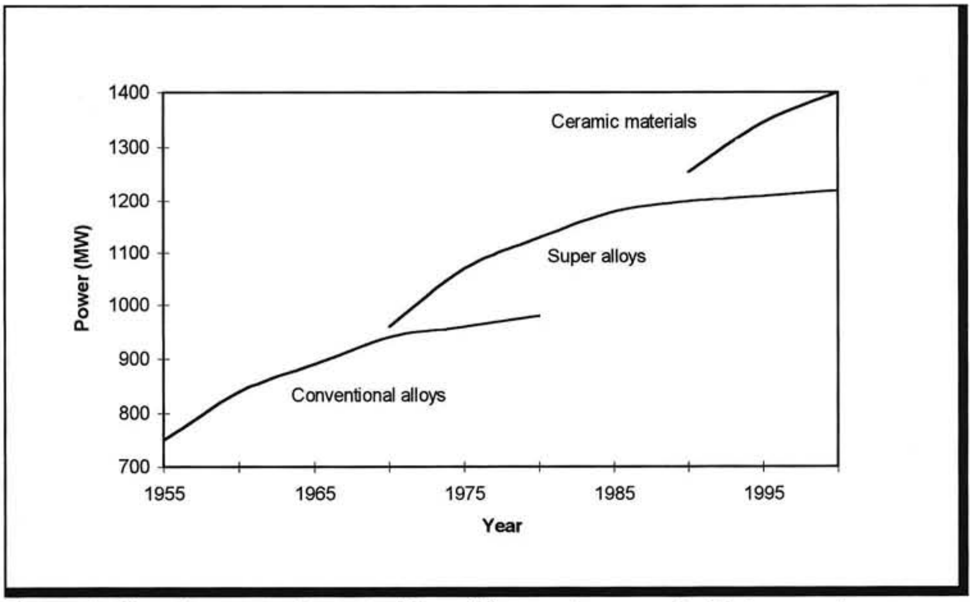


Figure 6: Development of gas turbines (2), maximum material temperatures

		Gas turbine	Diesel
Specific power	(kW/kg*sec)	245	575
Specifid weight	(kg/kW)	0.6	2.5
SFC	(g/kWh)	265	215
Output speed	(rpm)	13,000	1,900
Combustion air requirements	(kg/sec*MW)	4	2
Heat rejection	(kJ/min*kW)	0.7	3
Seawater cooling requiments	(kJ/min*kW)	1.3	30
Vibration levels	(μm(p-p))	50	100
Noise emission	(dBA)	105	115

g/kWh	Gas turbine	Diesel
NO_x	1.5	6.0
CO	0.9	1.9
UHC	0.1	1.5
SO_x	0	fuel dependant
TSP/Smoke Bacharach	2.0	4.0

Table II: Comparison of performance parameters and engine emissions

US$/MWh	Industrial derivative Gas turbine	Diesel engine	Aero-derivative gas turbine
Capital	27	20	44
Fuel	61	48	63
Oil	<1	10	<1
Maintenance	8	10	12
Subtotal	**96**	**92**	**119**
Revenue gain/Weight reduction	45	0	58
Net cost	**51**	**92**	**61**

Assumptions
- 10 years, 3000 hours annually
- US$ 5/pax-hour, 65 percent load factor
- 227 kq eq/pax wt
- US$ 0.20/litre fuel
- US$ 1.25/litre oil

Table III: HSLC engine operating cost comparisons

Steam turbines

The performance of engines is a very important issue in shipping, in particular the specific fuel oil consumption (expressed in grams per kW. (or HP) hour. The closure of the Suez Canal in 1956 triggered the phenomenal increase in size of oil tankers. The first supertanker (100,000 dwt.) from the American Ludwig built in 1960 could only be powered by steam turbines, as diesel engines did not have sufficient power on one shaft. The drawback of steam turbines was the low fuel efficiency, but in a period of cheap oil, this did not really influence the economy of the ships equipped with turbines. This lasted until the first oil crisis in 1973, which caused a steep increase in the price of oil and made in one stroke the turbines obsolete. **Figure 7** shows the development over time of the number of turbine tankers delivered. The figure resembles almost perfectly the standard product life cycle, which makes a full circle.

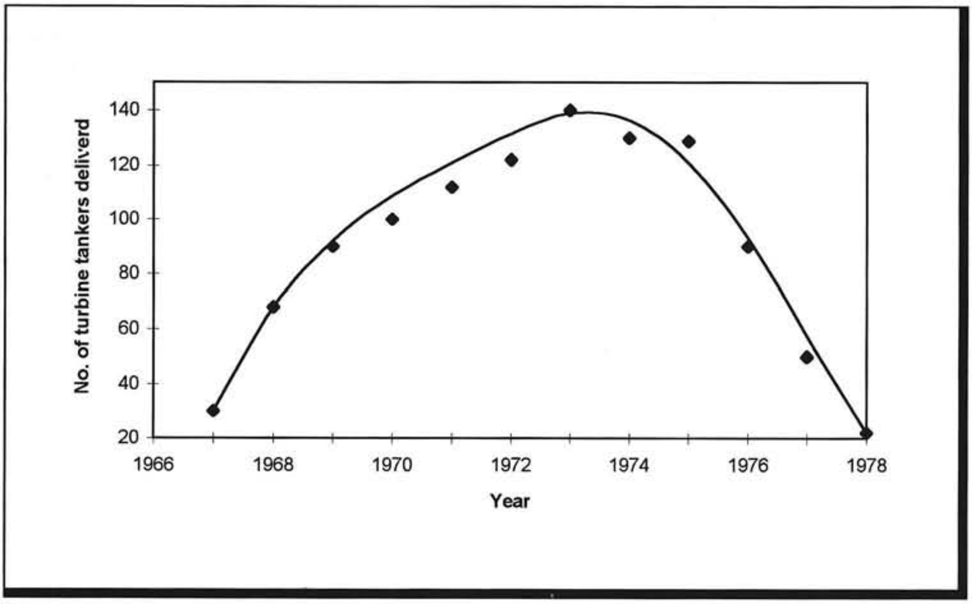


Figure 7: Development of the number of turbine tankers delivered

The history of the development of steam power and screw propeller ships provides many examples of S-curves, as is illustrated by the book *"The Advent of Steam; The Merchant Steamship before 1900"*. The ultimate in steam engine design was the 1900 built *Deutschland*, equipped with a quadruple expansion engine (**Figure 8**).

It also painfully illustrates the discontinuity of the S-curve, caused by a sudden shift in technology, in this case the invention of the Diesel engine in 1892. At that time the engineering skills had improved the steam engine to a very high

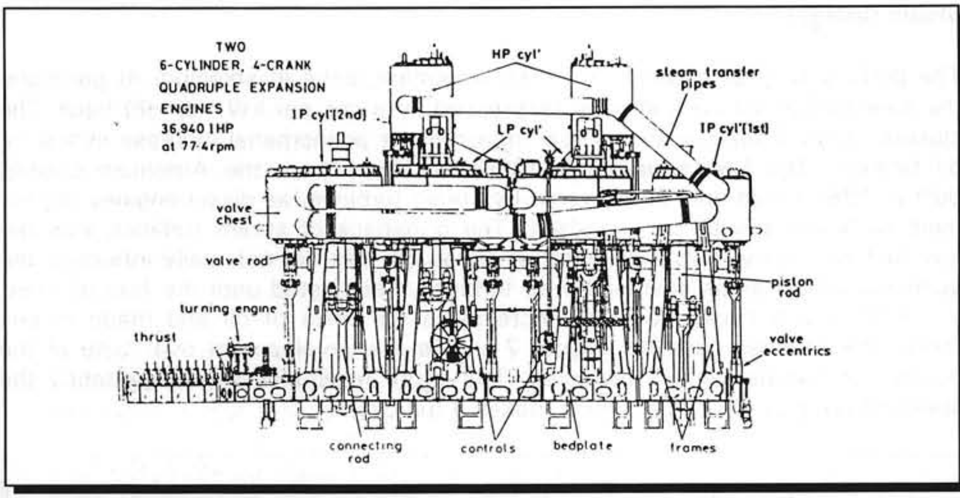


Figure 8: Quadruple expansion engine

standard. **Figure 9** shows three succeeding S-curves for the sail ships, steam ships and motor ships.

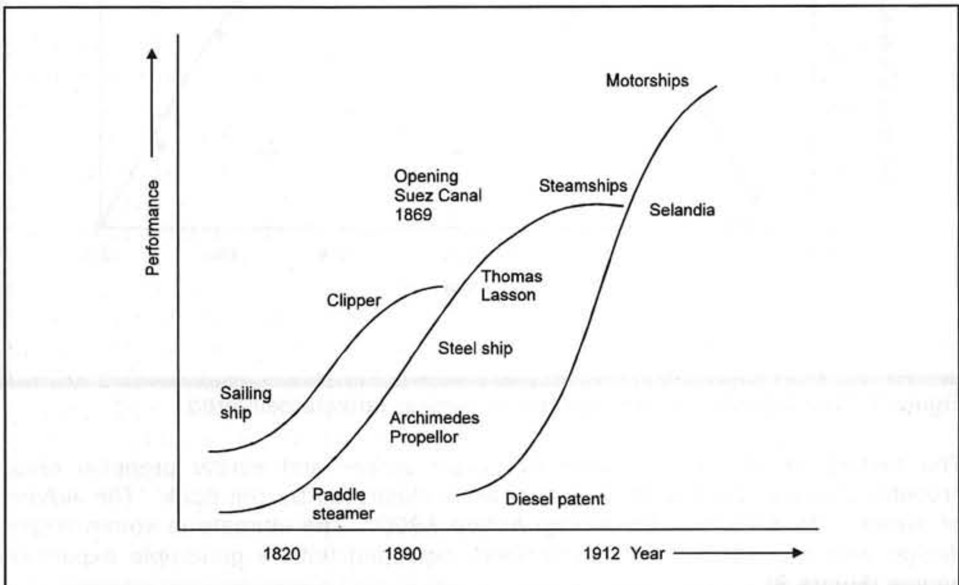


Figure 9: Shift in technology

Fast container feeder vessel

High speed of a small vessel results in a large fuel consumption, which reduces the economy of the design. In order to improve the relationship between payload-speed-fuel consumption of container ships, the German yard Blohm & Voss has developed a challenging monohull design, based on the marriage of two low-resistance concepts into a unique hull, which is shown in **Figure 10**.
The resulting designs of large feeder vessels, with a rated capacity of approximately 720 TEU (14 tons homogeneous) is shown in **Figure 11**, and resembles a deck carrier. This has a number of advantages:

- The structure of such a ship is in general simpler and lighter because one can dispense with heavy and expensive structures in the vessel's upper girder system, which normally is used to solve the torsional problems of the hull;
- There is no heavy and expensive structure for hatches and hatch covers;
- The cell guides, if required, may be arranged at any position, because they are not integrated in the vessel's carrying structure. It is a hybrid vessel, between the hatchless type and conventional container ship.
- The design has a very high speed, moderate propulsion power, high deadweight, almost no need for ballast water, easy and quick access to containers, extensive flexibility in container sizes.

Blohm & Voss has developed a version with a service speed of 22 knots, which results in a fuel consumption (IFO 380) of 60 tons per day; a service speed of 23.8 knots results in a steep increase in fuel consumption: 90 tonnes per day; the fastest version, 26.5 knots, uses about 135 tonnes per day.
In spite of the unique, low resistance hull form and the large payload for a fast freight vessel, the fuel consumption doubles with a modest increase in speed from 22 to 26.5 knots, which equates to US$6000 per day extra. This clearly illustrates the economic performance limit of fast freight vessels.
A 720 TEU container ship with a speed of 18 kn and a fuel consumption of 30 tonnes, has a charter hire of approximately US$9000 per day. The increase in speed from 18 to 23.8 kn (thirty percent), increases the fuel consumption with 60 tonnes or roughly US$6000 per day; the increase in speed to 26.5 kn (fifty percent) results in an additional fuel consumption of some 100 tons, or US$10,000 per day. It will be clear that in a competitive market, it will be difficult to justify such an increase in speed on the basis of faster premium cargo.

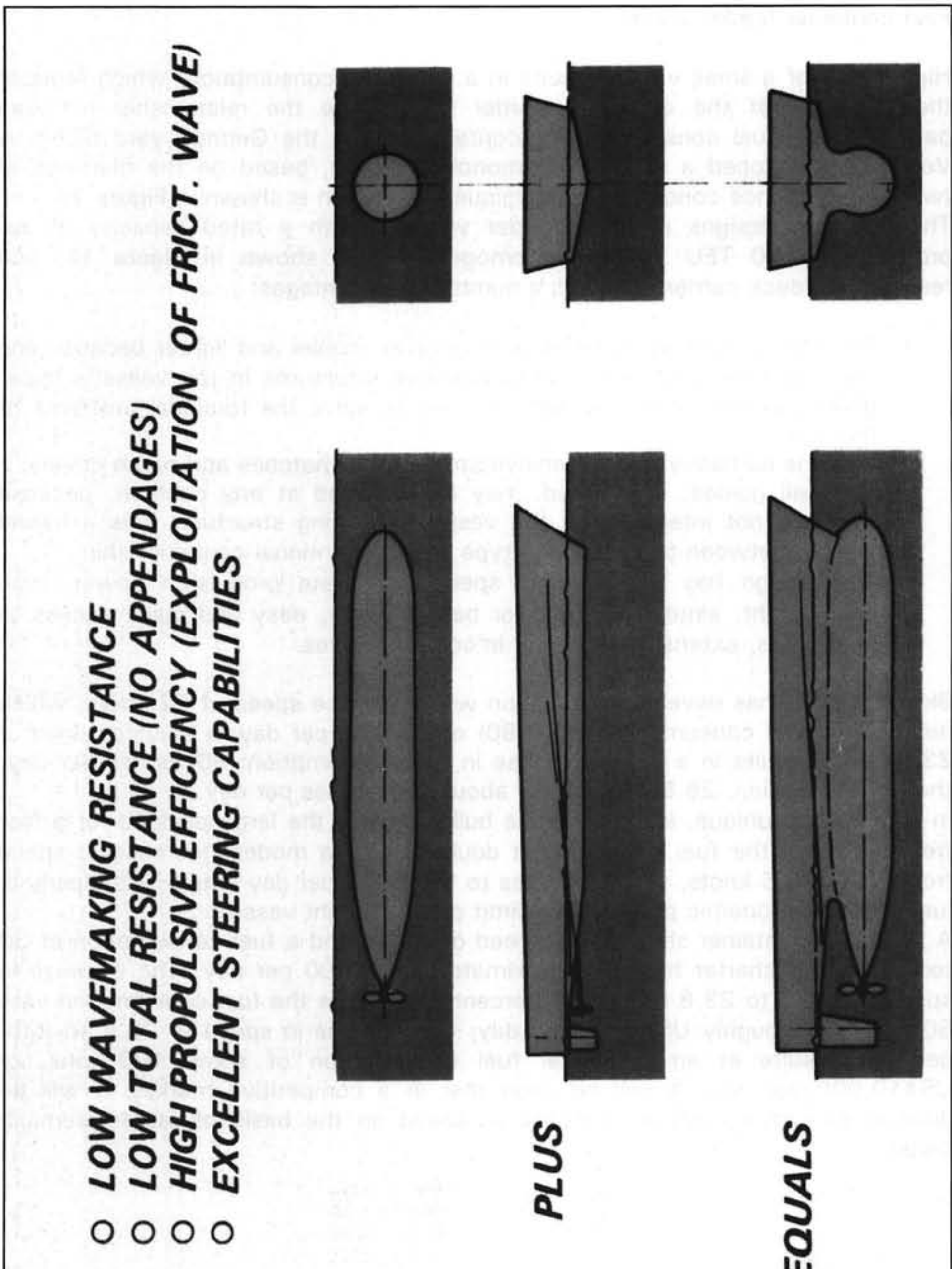


Figure 10: The hydrodynamical conception

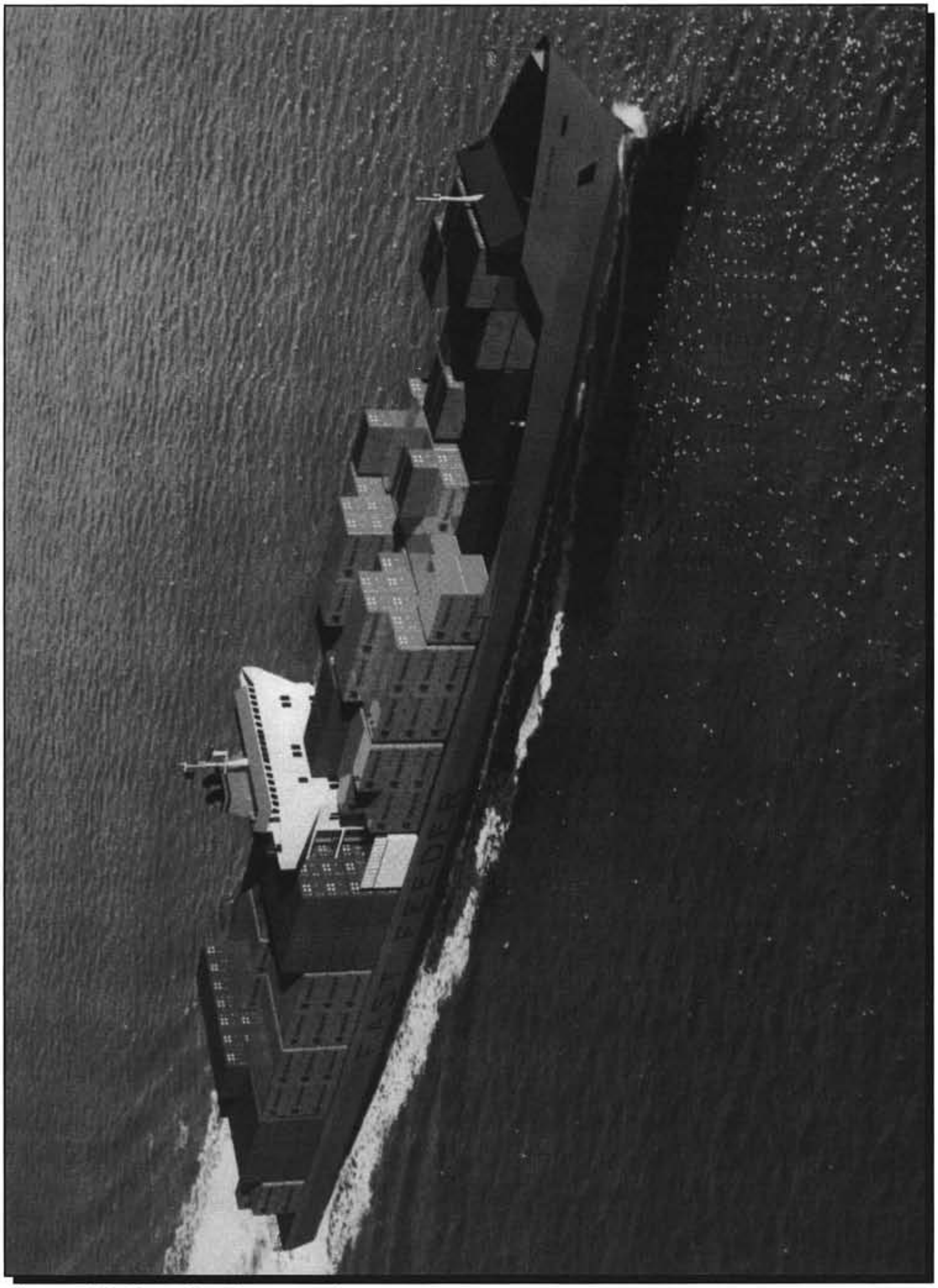


Figure 11: Fast feeder vessel

7.3 Performance limits and innovation triggers

In 1893, the world one hour cycle record stood at 35 km.; a century later, it had increased to approximately 53 km (**Figure 12**). This increase is not only due to a better physical condition of the racers, but rather to technological development in cycle design and composite materials.
It is anybody's guess to define the limit of this performance, but the figure suggests that the 50 percent increase over the last century is unlikely to be repeated over the next century. The limit of the S-curve is in view.

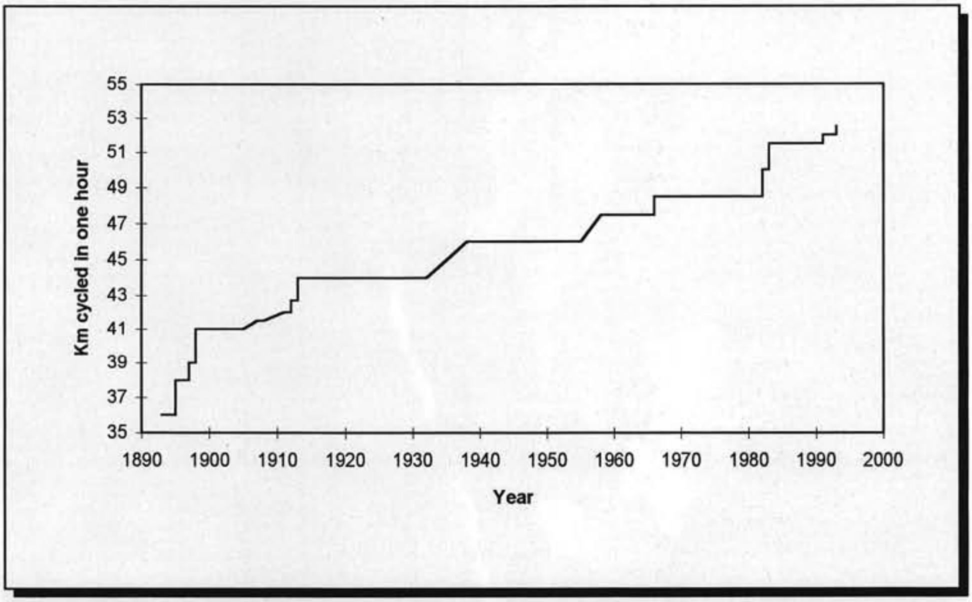


Figure 12: Development of the world one hour cycle record

Finding the limits of a specific product, process or technology is a major challenge and in practice quite difficult. Foster spends a chapter in his book on *limitry*, the limiting mechanism, and their fundamental principles that will ultimately stop progress. Innovation requires therefore first of all research that defines and finds limits. Once these limits are understood, they will give direction to R&D and form the trigger for innovation.

In shipping we can observe all sorts of limits, which can be classed into six categories of ***triggers***. These are:

1. Physical laws triggers;
2. Geographical conditions triggers;
3. Economic parameters triggers;
4. (International) regulations triggers;
5. Related sectors triggers;
6. Design concept triggers.

7.3.1 Physical laws triggers

The physical reality of our planet earth dictates a large number of conditions, which form in itself triggers for innovation. For example: resistance in water limits the speed of ships. There are three basic ways to overcome this physical phenomenon, as shown in **Figure 13**.
Static lift, or buoyancy support is the standard way to keep ships afloat. The other extreme is powered lift such as the lift of the helicopter. In between buoyancy and powered lift, stands dynamic lift: forward motion is converted into vertical lifting forces that reduces the wetted surface of the ships and consequently its resistance. Other examples are the specific weight of water and air, the air pressure, the temperature, and gravity.

The specific weight of water is a factor that limits the carrying capacity of ships, based on the law of Archimedes that the upward pressure on a submerged body is equal to the displaced volume times the specific weight of the liquid. Ships have a different deadweight capacity in salt water, or in very cold water, when the density increases.

An airplane is supported by air and its speed is restricted by the resistance of the air and up to a certain level, the speed of sound. Normal subsonic airplanes stay below the Mach 1 speed-level, as the sonic boom, which is triggered by passing this physical limit, will destroy the plane. In order to approach the speed limit of Mach 1, it was necessary to calculate the aerodynamic forces just before this point was reached. It took a decade before the the last ten percent in speed increase towards Mach 1 was reached, and it was only possible through an extraordinary advance in the science of aerodynamics and computer processing power. The supersonic planes started a new development in aviation, as is illustrated by **Figure 14**.

The air pressure, which fluctuates from hour to hour following the high to low pressure cycle, linked to bad and good weather, influences the performance of engines. A lower outside pressure has in principle a negative impact on the engine output.

The outside temperature influences, as mentioned before, the specific weight of water, but also of fuel oil. **Figure 15** shows the relation between temperature and density of fuel oil. A cubic metre of fuel oil can differ therefore widely in

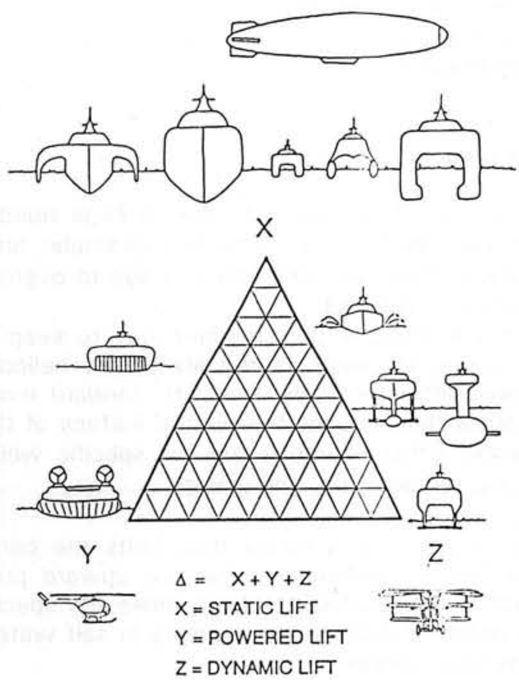


Figure 13: The lift triangle

energy content, not only based on the presence of water, sulphur or other pollutants, but also on the volume-weight.

Another phenomenon that we take for granted is the force of gravity, which is an important limiting factor in the design of ships. Ships plying the waves absorb a lot of energy from the wave motion, which is translated into movements. These movements, in turn, cause the acceleration forces on the ship, which vary over its length. **Figure 16** shows the vertical and transverse forces on a large container ship. The forces at the bow, may reach more than 2 times the forces of gravity, depending on the speed of the vessel. This has not only implications for the design forces on the ship, but also on the cargo.

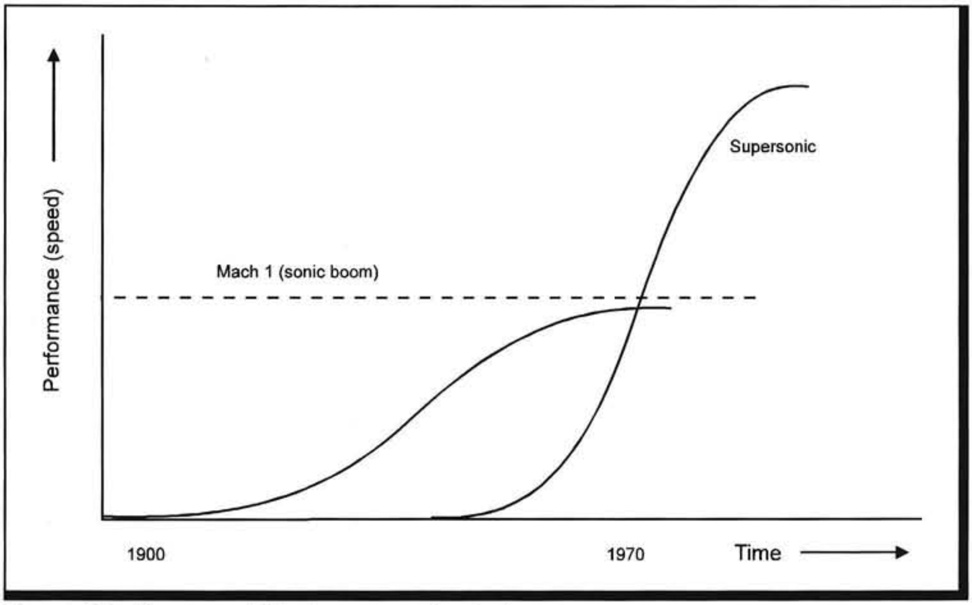


Figure 14: S-curve shift of supersonic airplanes

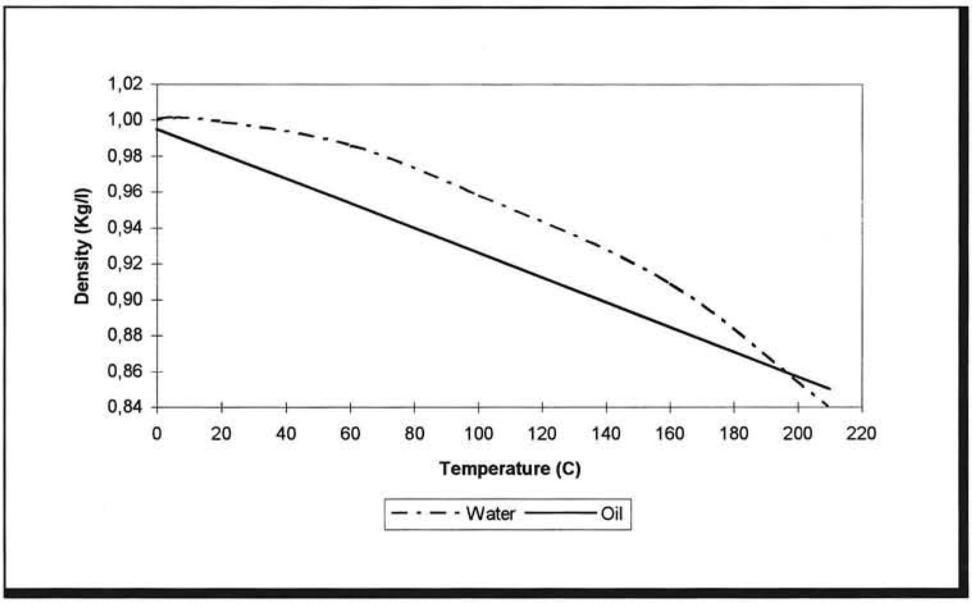
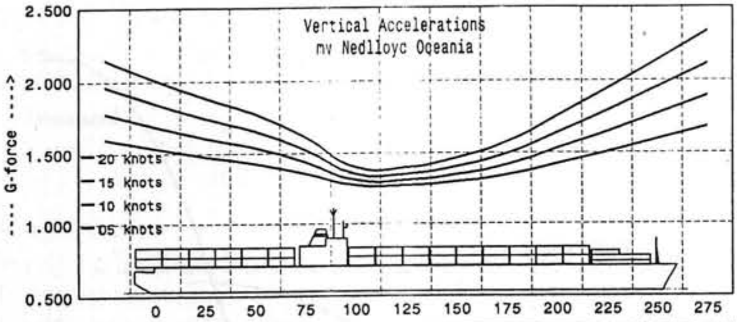
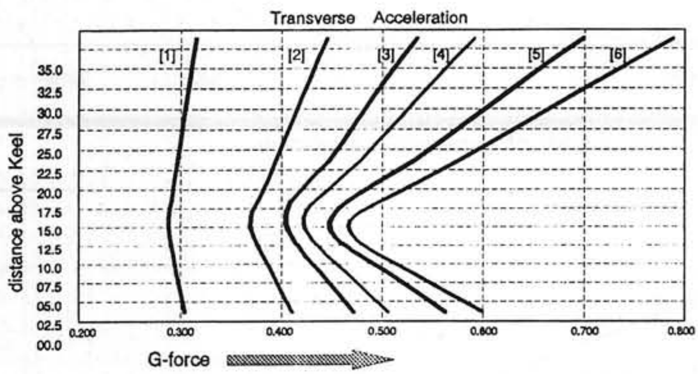


Figure 15: Relation between temperature and density of fuel oil



20 knots	2.148	2.010	1.884	1.776	1.615	1.401	1.397	1.463	1.574	1.756	1.943	2.133	2.332
15 knots	1.963	1.849	1.746	1.657	1.525	1.354	1.351	1.403	1.492	1.640	1.794	1.951	2.109
10 knots	1.780	1.690	1.609	1.540	1.439	1.311	1.309	1.347	1.414	1.528	1.647	1.770	1.895
05 knots	1.601	1.536	1.478	1.429	1.358	1.273	1.272	1.296	1.341	1.420	1.505	1.594	1.685

---- Distance from aft perpendicular ---->



[1]	0.316	0.312	0.309	0.306	0.303	0.300	0.297	0.294	0.291	0.288	0.288	0.285	0.298	0.300	0.304
[2]	0.446	0.436	0.428	0.419	0.411	0.402	0.394	0.346	0.377	0.369	0.372	0.381	0.391	0.400	0.410
[3]	0.633	0.618	0.604	0.490	0.478	0.462	0.448	0.434	0.420	0.404	0.410	0.426	0.440	0.448	0.471
[4]	0.690	0.671	0.583	0.534	0.518	0.497	0.479	0.461	0.443	0.422	0.427	0.446	0.466	0.485	0.506
[5]	0.698	0.670	0.643	0.615	0.587	0.559	0.532	0.504	0.477	0.449	0.453	0.480	0.507	0.534	0.561
[6]	0.766	0.793	0.718	0.682	0.647	0.611	0.578	0.643	0.606	0.470	0.463	0.487	0.531	0.564	0.588

Figure 16: Acceleration forces on the ship

The engineers are so used to apply standard values for water resistance, air pressure, water density or g-forces, that they do not realise to what extent these physical parameters determine the basic design principles of ships. Try to imagine for example the impact on a ship design of a g-force that is double the present value, or a water density that is half the present value.

7.3.2 Geographical conditions triggers

Physical limits have been around for millions of years, as is the case with some of the geographical conditions that are relevant to shipping. Usually, these are draught restrictions for access to ports, or passages in Straits, but can also be in the form of ice barriers. A number of geographical conditions are manmade, such as the Panama Canal, Suez Canal, or the St. Lawrence Seaway, which give access to the North American Great Lakes.
Besides, many terminals (chemicals, gas, oil) in the world pose limits to ships, as far as length, breadth, and draught are concerned. A good example is the development of the sea-river ships, which sail many rivers in Europe. They have a limited water and air draught, which make it possible to navigate rivers and seas.
Another important geographical conditions trigger is the significant wave height in a particular area of the world. Some ships are designed only for a modest wave height; they have a restricted sailing certificate. An example of this class of ships is the sea-river ship, which for example in Europe, is not allowed to sail beyond Brest in France.
The ice conditions triggers the development of Ice-class ships, which have a special bow section and increased engine power.

There are many ship categories designed on the basis of these geographical restrictions, such as the Panamax bulk carriers, the Capesize bulk carriers, the Suezmax tankers, the Aframax tankers, or the VLCCs. Geographical limitations, either natural or manmade, create strong triggers for shipowners and ship designers to innovate. A number of case-studies in this book are examples of this trigger.
It is important to note that most of the ships in the world fleet are some way or other influenced for their length, breadth, or draught by geographical restrictions. It is therefore important to identify these restrictions in the design process.

The engineers should also bear in mind that conditions may change over time, which may impact fundamentally the economics of ship design. An illustration of such an event was the plan of the Suez Canal Authority (SCA) to expand the width and draught of the Canal in order to allow for loaded VLCCs with draughts of up to 68 feet to make the 195 km. long transit. Such an expansion would have meant 260,000 dwt. VLCCs could avoid sailing around Cape of Good Hope, thereby reducing the journey from Ras Tanura (Persian Gulf) to Rotterdam by some 14 days.
However, feasibility studies from SCA have shown that the investment required for the project would not have an attractive return. The Canal will by the end of 1996 be able to accept vessels with draughts of up to 59 feet, which includes all vessels up to just short of VLCC size.

Some years ago a group of six Norwegian companies, coordinated by R.S. Platou, set out to design a new type of oil tanker, the so-called ECO-tanker. The aim of the consortium was to design an oil tanker that has:

- Double hull, reducing the risk of oil spills, caused by collisions or groundings;
- Simpler welding work for lower construction cost
- Less steel for lower construction cost and for increased carrying capacity;
- No internals in cargo tanks for easier cleaning operation;
- Better resistance against cracking in the cargo tanks;
- Increased cargo cubic for higher payloads;
- Reduced draught in relation to payload;
- Larger ballast water capacity;
- No webs or girders on deck for easier maintenance;
- Reduced wet surface of the hull for better speed/consumption ratio;
- Reduced cargo tank surface for cheaper coating and maintenance;
- Reduced slamming forces from cargo in tanks.

These ambitious objectives resulted into a revolutionary design, which is shown in **Figure 17**. The cross-section and steel structure are shown in **Figure 18** and **Figure 19**. Several designs were made, such as a 107,500 dwt. tanker, a 155,300 dwt. Suezmax tanker and a 280,000 dwt VLCC.

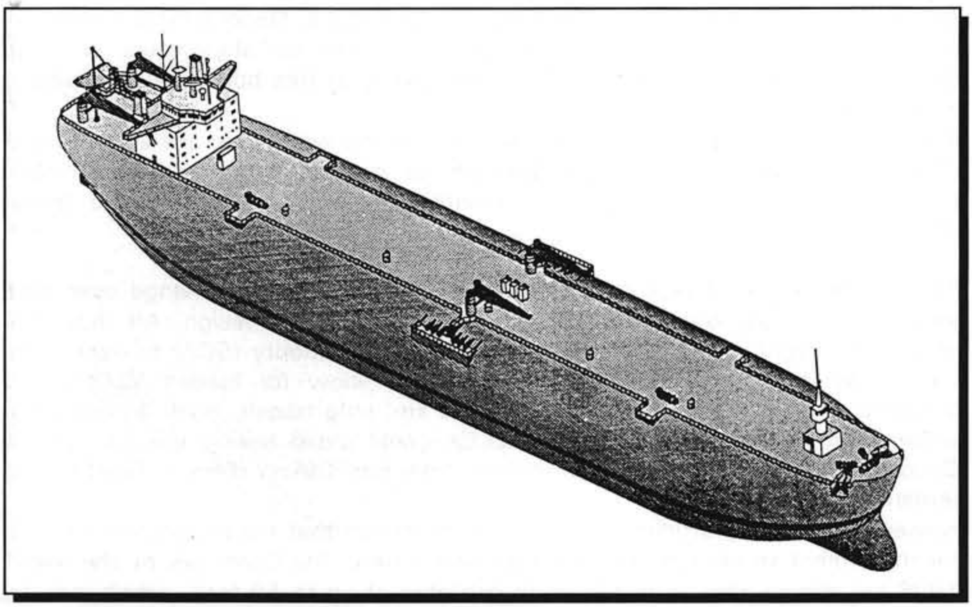


Figure 17: General arrangement of the ECO-tanker

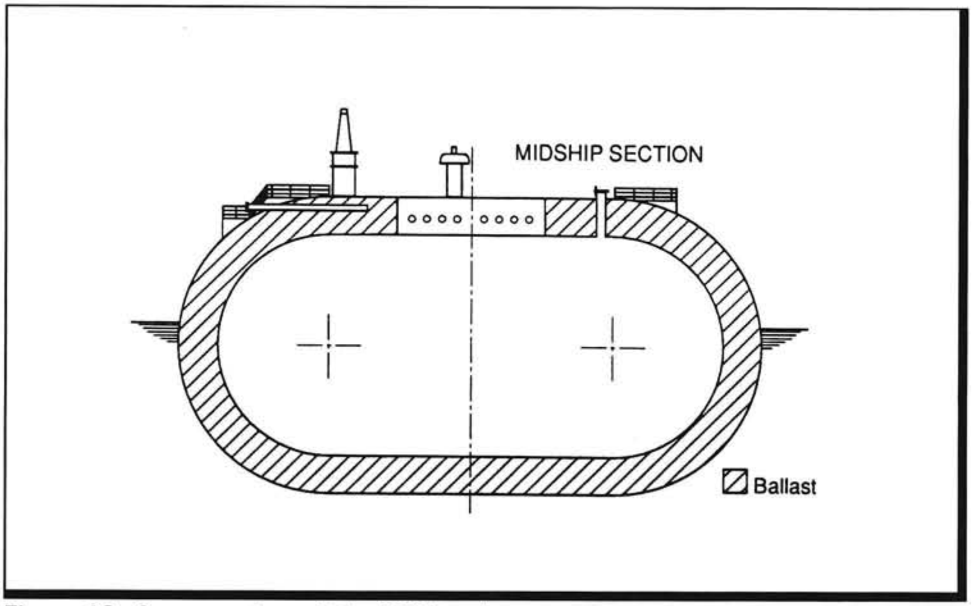


Figure 18: Cross-section of the ECO-tanker

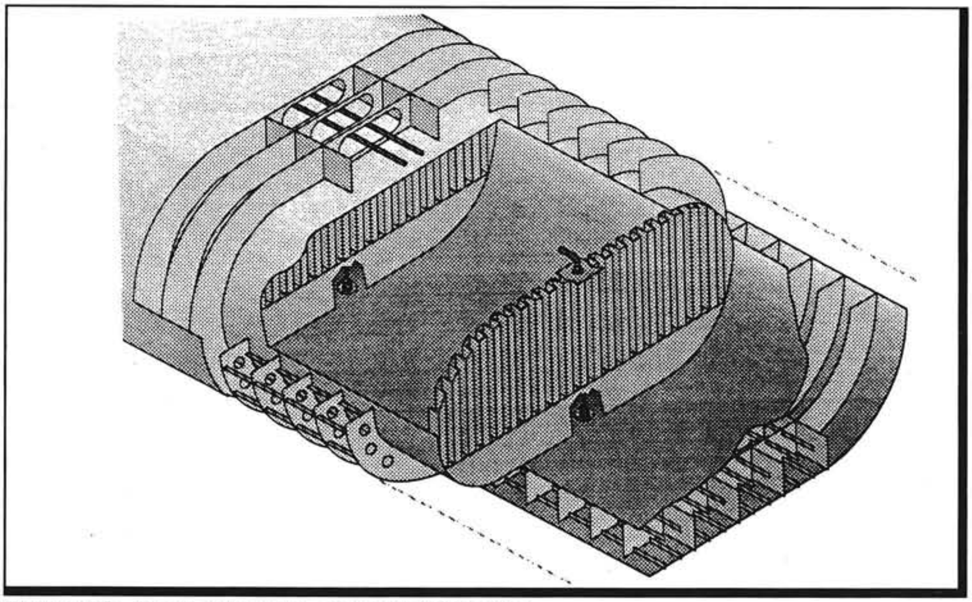


Figure 19: Steel structure of the ECO-tanker

The designs lived up to the design objectives, as mentioned above. Tank test showed that the seakeeping capabilities were good. The Suezmax design could increase its carrying capacity, at the accepted draught in the Suez Canal. The consortium convinced the Suez Canal Authority that the favourable hull shape could safely lead to an increase in the allowable draught for the canal transit. **Figure 20** shows the ECO-tanker in a typical cross-section of the canal; **Table IV** compares the Suezmax ECO-tanker with a conventional oil tanker. The negotiated draught of 16.2 m for the ECO-tanker presented at that time an additional payload of some 17,000 ton crude, an amount that can give owners a competitive advantage.

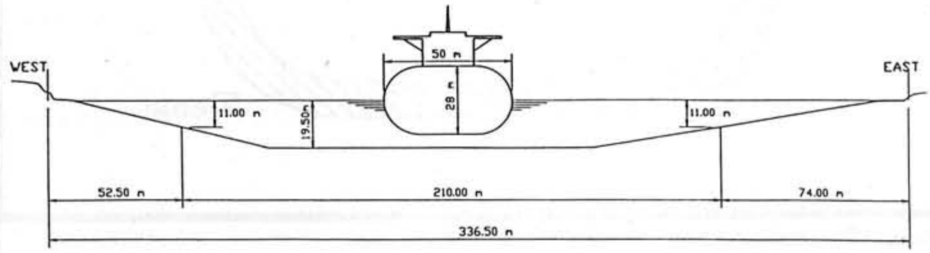


Figure 20: Cross-section of ECO-tanker in Suez canal

		Conventional tanker	Eco-tanker
Lenght over all	(m)	274.0	274
Breadth	(m)	46.3	50
Depth	(m)	22.5	28
Scantling draught	(m)	16.9	17.1
Cargo volume	(cum)	162,200	183,000
Deadweight scantling draught	(tonne)	156,200	166,800
Deadweight Seuz accepted draught	(tonne)	138,100	145,000
Deadweight Seuz negotiated draught	(tonne)		155,300
Crude intake max. Seuz at 7.5 BBLS per tonne	(BBLS)	1,020,000	1,070,000
Crude intake negotiated draught 16.2m at 7.5 BBLS per tonne	(BBLS)		1,150,000

Table IV: Dimensions and capacities

In spite of the apparent advantages, the concept could not be sold to the shipowners and yards. The uncertain construction aspects and costs of the revolutionary hull form, was a too big risk, especially in a bad charter market, as prevailed at that time and still does today. The example illustrates however, the process of seeking a competitive advantage in design and operation of ships, and the kind of triggers, or benchmarks that are relevant.

7.3.3 Economic triggers

Maximisation of revenues can be achieved by design of a flexible, multi-purpose ship that can carry for example dry bulk and containers. The Dutch in particular have developed these box-shaped ships. But also sto-ro or ro-ro vessels create flexibility. The container-oil-bulk ship is yet another example of ballast voyage minimisation, or revenue maximisation.

Economy of scale is a major trigger for innovation. Large ships have significant lower investments per tonne, as well as lower running and voyage costs. So indirectly, the search for economy of scale is triggered by cost reduction objectives. The increase in the average size of the shortsea fleet shows the importance of this trigger

Cost reduction
Capital investment: The reduction of capital cost can be achieved, not only through economy of scale, but also through standardisation. This is for example achieved by several shipyards that have developed a standard design. They can realise important cost savings through smart engineering and production, as well as the experience gained on the learning curve.

Running costs: The major item in the running costs is the crew cost, which is determined by manning regulations. These, in turn, are related to the training level of the crew, the complexity of the engine room and the size of the ship (measurement), besides, the flag of registration and the nationality of the crew. Important efficiency improvements have been achieved in order to reduce the running cost.

Voyage costs: Two major items in this category are: bunkers and port costs. Bunker costs depend on many factors, such as the deadweight of the vessel, blockcoëfficient, speed and type of fuel. Major improvements have been achieved to improve the fuel-economy.
Port costs are not uniformly calculated in ports around the word. Most of the ports relate these costs to the measurement of the vessel (gross tonnage). Shortsea ships call very frequenly in ports and the reduction of port costs through creative lowering of the measurement of shortsea ships has been, and still is, an important trigger for innovation. This has also led to a situation whereby most of the cargo is carried on deck, and to a very low freeboard. A major change in port cost calculation principles would become an important trigger for innovation.

Cargo handling: Stevedoring costs are a major costs item in shortsea trades, as the sealeg is usually limited in length. There are two aspects that form triggers for innovation: the increase in labour productivity (tonnes/man/hour) and making ships independent from the availability of terminal labour. The 'goal-function' of any innovation in cargo-handling is to reduce these costs to zero, as "*the best port is no port at all*".
The first objective, improving labour productivity, is achieved through more efficient cranes, on shore and on the ship, the use of cargo units such as the container, bulk bags and cassettes. The second objective, making the ship independent of terminal labour, is achieved by equipping the ship with self-loading and self-unloading equipment. This technique is mostly developed on bulk carriers and on cement carriers (loading and unloading, closed system).
The advantage of such a system is that the ship can enter the port/terminal any time of the day or week, without being penalised by extremely high stevedoring labour costs during the nightshifts, or weekendshifts. This is especially important for small, coastal ports. The selfloading and unloading of unitload ships is still in its enfancy. It is the subject matter of this book, and the last frontier of major innovation.

7.3.4 Regulations triggers

The abolishment of cabotage-regulations has been an important trigger for change, not so much in ship innovation, but rather market innovation. The wish to reduce the environmental pollution of transport results in an ever growing list of standards and regulations for emisson, etc. This leads to innovations that are much easier to implement on ships than for example on trucks, due to its large size. Besides administrative, political and environmental regulations, there are labour/manning regulations, each with its own impact, such as noise level reduction onboard.

An example of an important change in regulations with implications for shipping is the proposed Annex to MARPOL on Air Pollution, which should be in force by the year 2000. The use of CFCs, which are used in refrigerants on reefer ships, fishing vessels and gas tankers, should be eliminated completely by the year 2000, as well as the fire retardants based on halons. This kind of measures create strong incentives to innovate, although it is often difficult to find adequate replacements (as is for example also the case with the tin-free anti-foulings).
The production of SO_x, NO_x and CO_2 should be dramatically reduced as well by the year 2000. Major reductions can simply be achieved by using low sulphur fuel oil and using exhaust gas treatment plants on board in case of SO_x reduction. NO_x emissions are more difficult to reduce. **Figure 21** shows the relationship between NO_x emission and the engine speed for large diesel engines. New targets are being proposed to reduce NO_x emissions from diesel engines. This has become the domain of engine manufacturers and at the same time an

economic battle. Those manufacturers who have already researched low emission engines are keen to create and exploit their competitive advantage by setting low international standards. **Figure 22** shows the Japanese and **Figure 23** shows the Wärtsilä proposals for NO_x emissions.

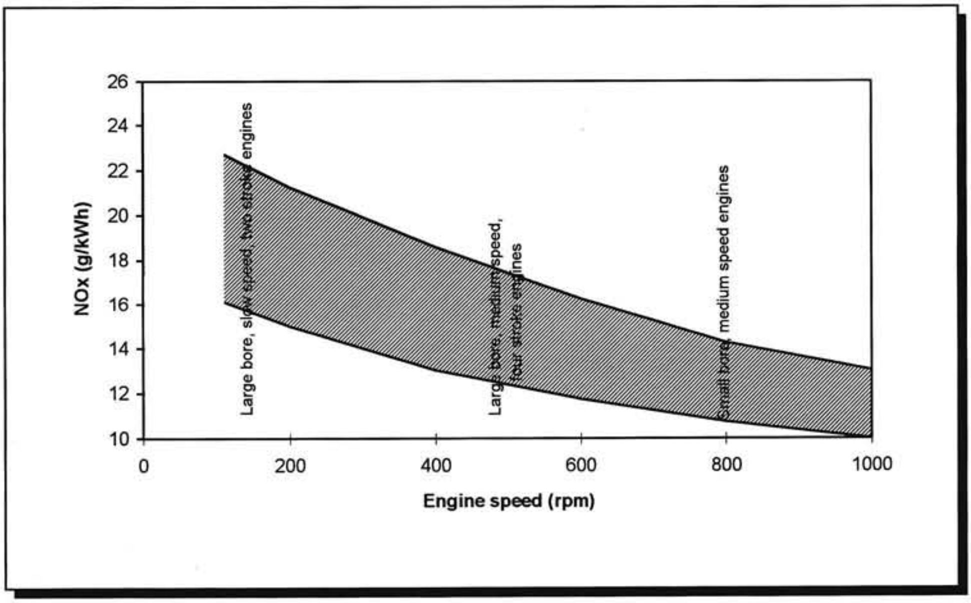


Figure 21: Emisson of NO_x for large diesel engines

Another good example of an innovation triggered by a regulatory change, is again based on Marpol, Annex V: the reduction of pollution from ship generated waste that is disposed of into the marine environment. According to this regulation, it is permissible to dispose of shredded glass and tins or food waste outside special areas overboard to sea. This has led to a whole range of new onboard waste treatment systems, which are schematically shown in **Figure 24** for a cruise or ferry vessel.

To get a feel for the dimensions of such a system, **Figure 25** gives an overview of the different types of waste produced per day by a 2500 pax cruise ship. The daily waste amounts to more than 6 tonnes, which can be reduced by the treatment system to less than half the weight, and 5% percent of the volume!

Ship measurement

The measurement of ships determines in many ports around the world the level of port dues, or in canals, the canal dues. Minimising the measurement has therefore been a strong trigger for ingenuity in ship design. Ingenuity, not innovation, as the design based on the measurement reduction, often led to strange and even dangerous ships, with little or no freeboard. To take the argu-

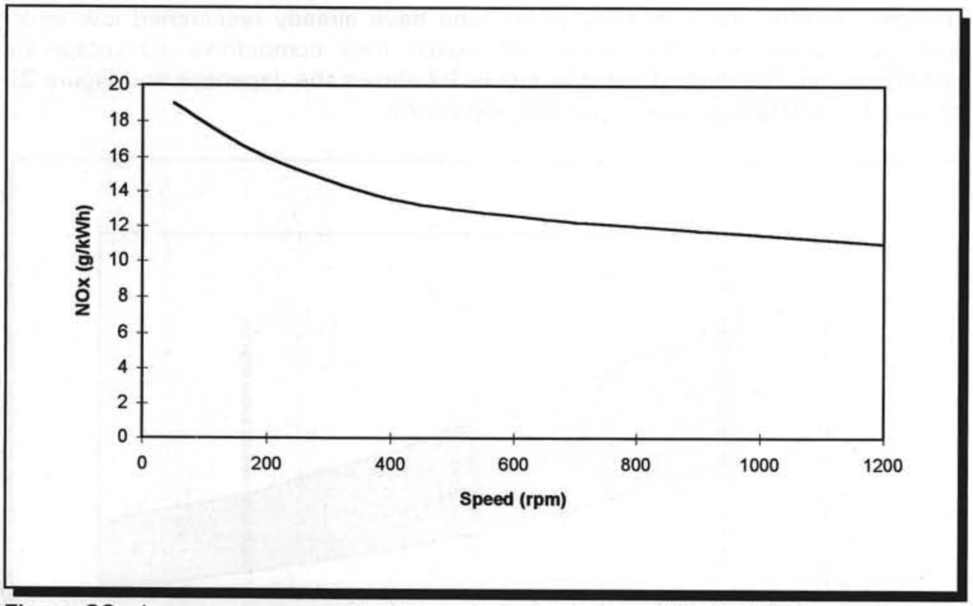


Figure 22: Japanese proposal to international maritime NO_x legislation

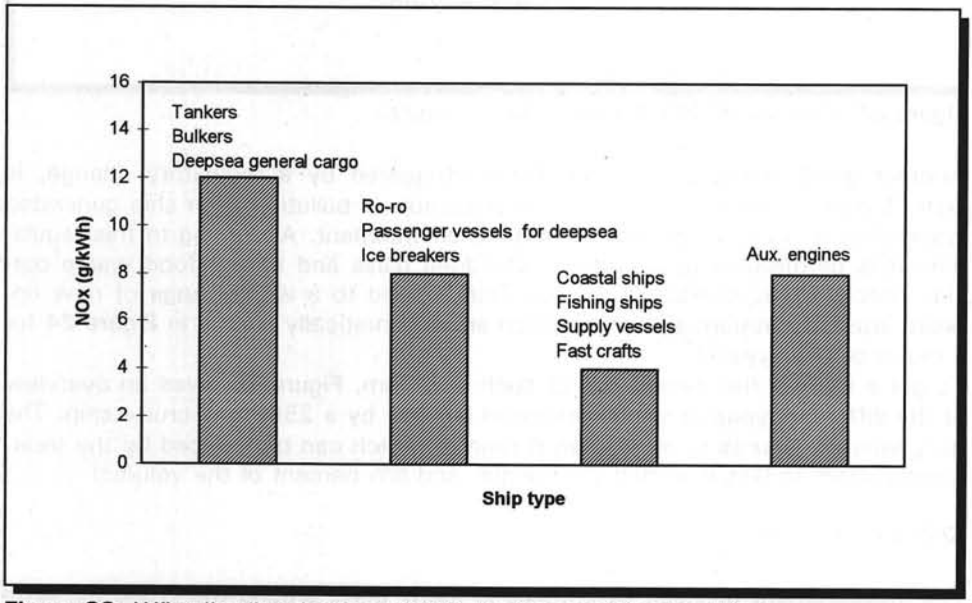


Figure 23: Wärtsila diesel proposal NO_x limits according to ship type

ment one step further, the measurement of ships has played and still plays a negative role in design innovation in ships. The example of very safe high

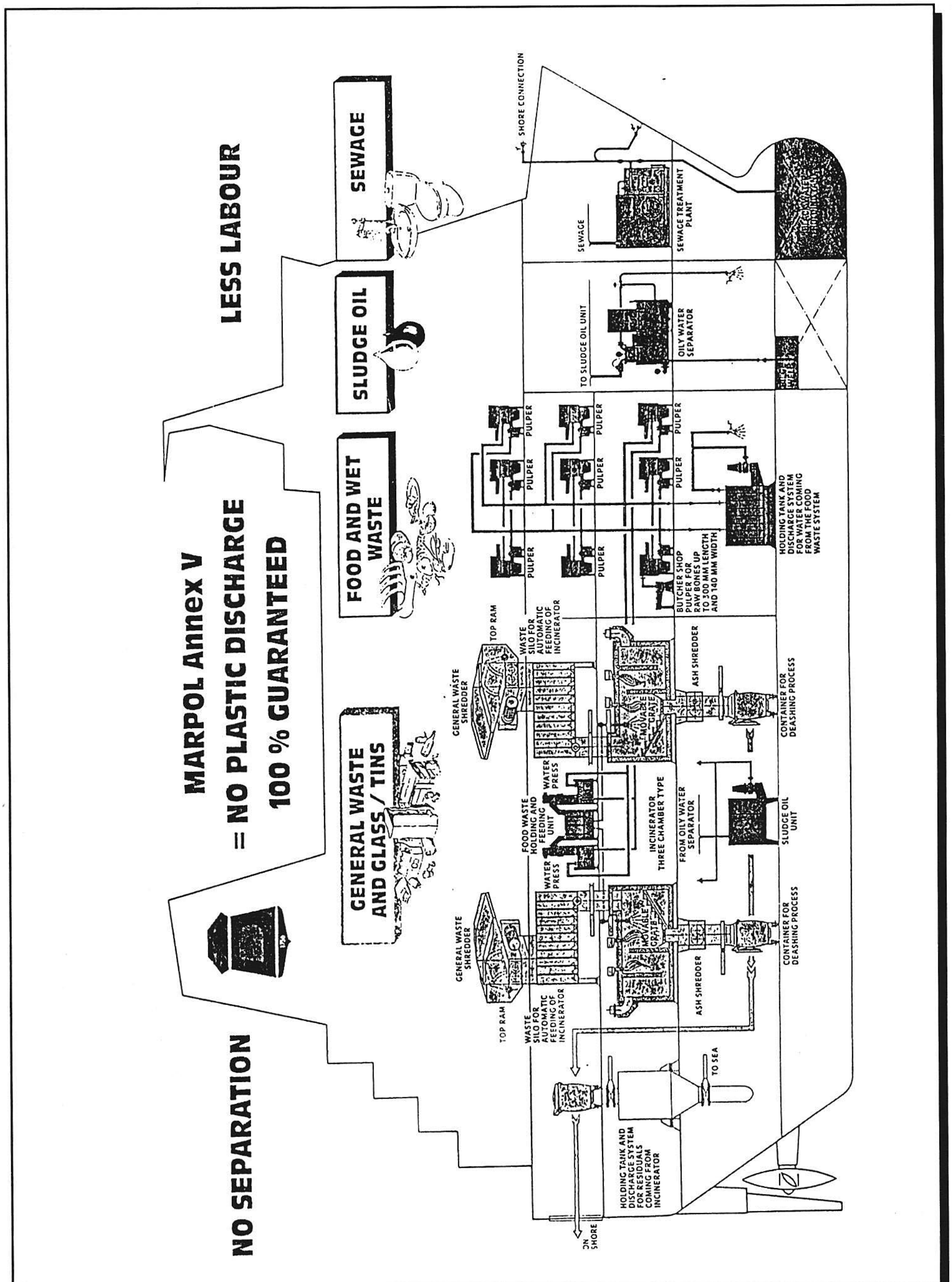


Figure 24: Onboard waste treatment systems

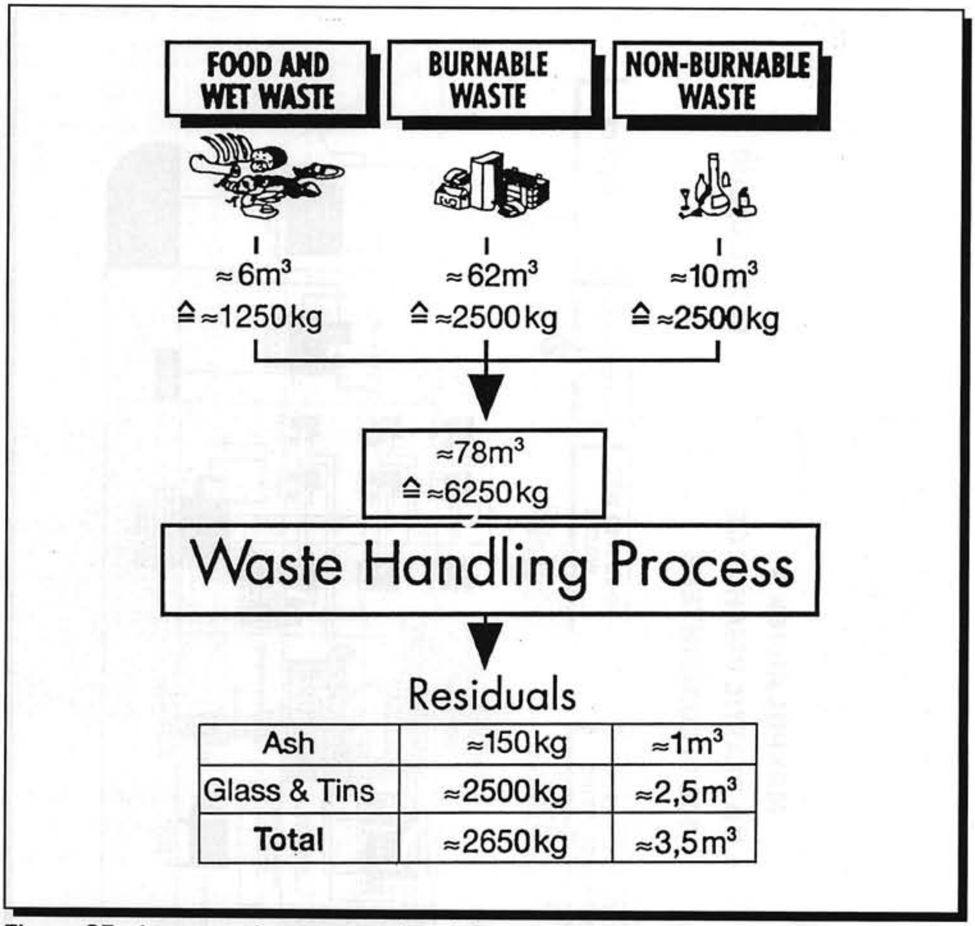


Figure 25: Amount of waste produced by a passenger ship

freeboard, hatchless container ships demonstrates that owners face a penalty in port for safe and sound design of ships. Another example is the increased measurement of double hull ships and the penalty in higher port and canal dues, based on this increase. Although some ports have corrected these anomalies.
Before the tonnage measurement is briefly discussed, an examples from the past, the turret ship, will show that owners have only one thing in mind, cost reduction.

Turret ships

In *"The Golden Age of Shipping"*; The Classic Merchant Ship 1900-1960 the development of the so-called turret ships demonstrates that owners were already around 1900 very sensitive to minimising of measurement. **Figure 26** shows the submarine-like ship, and **Figure 27** shows the cross-section. The first ship of this type was built in 1892 and the last in 1911, during which period 170 ships were built.

Figure 26: The turret ship

The turret class ships got their name from her hull form and the superstructures on top of it. The hull, which sat low in the water, had very curvaceous sides and a snout shaped bow. Completely flush, even to hatch covers, she carried several tall erections or *turrets*, the longest of which was built over the machinery space and contained the accommodation and wheelhouse.
Besides its inherent strength - helped by a cellular bottom (!) - the turret design was the more popular with owners since its net tonnage was low in relation to deadweight; also that Suez Canal dues were based on the breadth of the upper deck and not on the much wider main (or harbour) deck below. Amended regulations eventually rectified this and so, in 1911, the construction of turret steamers came to an end.

<u>Tonnage measurement</u>

This section is based on the article *"Tonnage measurment"* in Seatrade review, april 1994. What is a ship's tonnage? In shipping terms a tonne can be expressed in two forms:

- A physical weight (1000 kg. metric) for deadweight and displacement measurements;

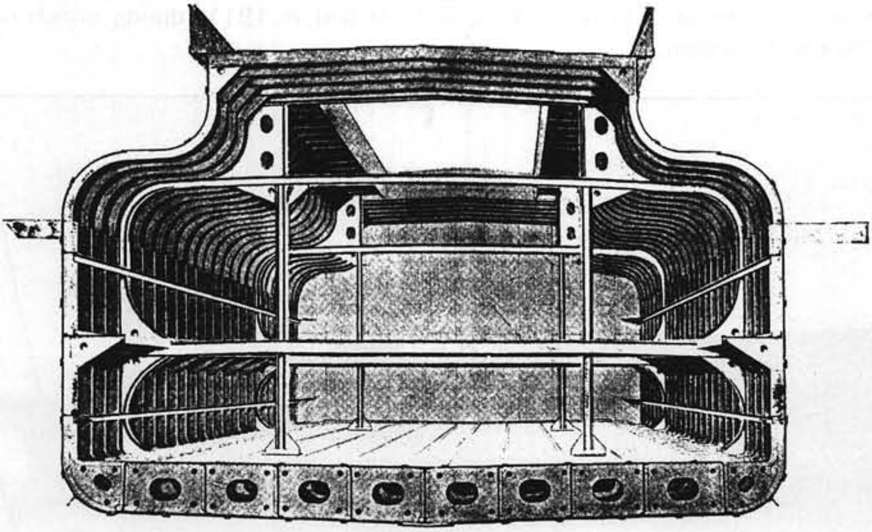


Figure 27: The turret ship cross-section

- A reflection of volume - gross registered and net registered tonnages (grt/nrt) - expressed in hundreds of cubic feet.

The origins of the grt/nrt date back to the mid-19th century when a Royal Commission was set up to seek alternatives to the way ships tonnages were measured. The then Surveyor General for Tonnage, recommended a volumetric system for all enclosed spaces using 100 cubic feet as one gross ton. Deductions were made to the gross tonnage of non-revenue earning spaces to arrive at the net tonnage which represented the earning potential of a ship and upon which charges would be levied. The recommendations were adopted in the U.K.'s 1854 Merchant Shipping Act and since then have formed the basis of many of the world's national tonnage regulations.
The original concept was designed to accommodate the fairly simplistic designs of ships then trading. Changes in the way ships were constructed soon meant that amendments had to be made and in addition, individual countries began applying their own interpretations to the idea. This resulted in twelve major methods worldwide of tonnage measurement.

London 1969 Tonnage Convention

As off July 18, 1994 grt and nrt measurements have been officially replaced by new definitions: gross tonnage (GT) and net tonnage (NT), as laid out in the London 1969 Tonnage Convention, see Chapter Notes. Why was it necessary to adopt a universal tonnage measurement?

With a number of differing national tonnage regulations in place, the sale of a ship often meant that she would have to be remeasured before adopting a new flag. Because measurements were conducted on site, these changes could be both time consuming and costly.
Another peculiarity is the ro-ro vessel. Under some national rules only spaces below the deck which runs from the main opening are counted, while under others it may be the uppermost continuous weather deck (**Figure 28**). A pair of exact sister ships can therefore differ in tonnage depending on registration.

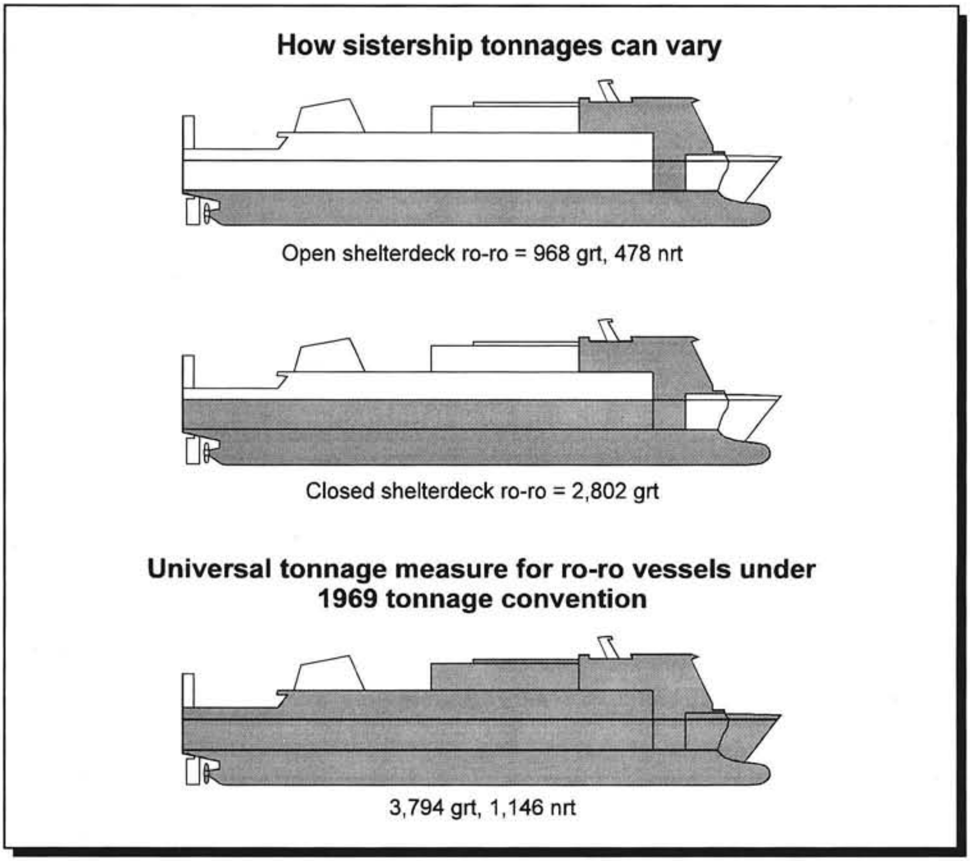


Figure 28: Differences in tonnage depending on registration

Under the 1969 Tonnage Convention, the Gross Tonnage (GT) and Net Tonnage (NT) are calculated in cubic meter on the basis of the following formulas:

$$GT = k_1 * V \tag{1}$$

Where:

V = The total volume of all enclosed spaces of the ship in cubic metres

K_1 = $0.2 + 0.02\ {}^{10}log\ V$

$$NT = K_2\ V_c\ (\frac{4d}{3D})^2 + K_3\ (N_1 + \frac{N_2}{10}) \tag{2}$$

Where:

The factor $(\frac{4d}{3D})^2$ should not exceed 1

$K_2\ V_c\ (\frac{4d}{3D})^2$ should not be less than 0.25 GT

NT should not be less than 0.30 GT

and:

V_C = The total volume of the cargo spaces in cubic metres

K_2 = $0.2 + 0.02\ {}^{10}log\ V_C$

K_s = $1.25\ \frac{GT + 10{,}000}{10{,}000}$

D = Moulded depth in metres

d = Moulded draught midship in metres

N_1 = Number of passenger in cabins with more than eight bunks

N_2 = Number of other passengers

$N_1 + N_2$ = The total number of passengers that the ship is allowed to transport. If $N_1 + N_2$ is less than 13, N_1 and N_2 are considered to be 0.

Table V compares the tonnage measurement on the basis of the existing, national convention with the 1969 Tonnage Convention for the different ship types.

For some ship types the effect will be a slight decrease in measurement, while open shelter deck, ro-ro, passenger and ferries increase dramatically. The change in measurement should have an impact on the port costs of these ship types, although this might be mitigated when the ship sails on a regular shortsea schedule, as most of the ferries do. Then the owners will obtain special rates from the port authorities, which are thus not related to measurement. In general however, the measurement has a negative influence on sound design.
The example of the hatchles container ship was already mentioned, and it will be illustrated by the Nedlloyd Europa, a 3568 TEU ship. The IMO 1969 Convention states that this ship type should be measured applying a hypothetical hatchcover over the open hull. This results in a high GT in relation to deadweight (DWT). **Table VI** shows the comparison of large conventional con-

	Gross tonnage			Net tonnage		
Type	Mean national	Mean 1969	% Change	Mean national	Mean 1969	% Change
Tankers	36,825	35,017	(4.91)	23,291	23,795	2.16
Bulk carriers	17,132	16,532	(3.50)	10,257	8,640	(15.76)
Ore Carriers	11,820	10,948	(7.377)	5,197	3,591	(30.82)
Singledeckers	629	23	14.94	383	389	1.57
Closed shelterdeckers over 3,000 grt	8,523	8,796	3.20	4,883	4,505	(7.74)
Close shelterdeckers less than 3,000 grt	797	821	3.01	-	-	-
Open shelterdeckers over 2,000 grt	5,926	8,319	40.38	3,340	3,685	10.33
Open shelterdeckers less than 2,000 grt	332	821	147.29	217	310	42.86
Ro-ro ships closed	2,802	3,794	35.40	-	-	-
Ro-ro ships open	968	3,974	291.94	478	1,149	140.37
Passenger ships	15,231	15,319	0.58	8,292	6,604	(20.36)
Ferries	1,844	2,948	59.87	824	1,038	25.97

Table V: Comparison between national and 1969 tonnage conventions

tainer ships with the *Nedlloyd Europa*. The average ratio DWT/GT for conventional ships is 1.09, while the Europa has 0.96. That is unfair and for this reason, an amendment to the measurement was proposed and accepted, which resulted in a correction on the calculation.

7.3.5 Related sectors triggers

Innovations in areas, such as computers and datacommunications, in particular electronic data interchange (EDI) can impact the competitive position of shortsea shipping in a positive way.
Low cost networks between the shippers, receivers, forwarders, truckers, stevedores, customs and shipowners, can create a virtual integration and control of the broken transport chain, and compete therefore with simple point-to-point road/rail transport. Good examples of these EDI Networks can be found in the U.K. and other northwestern European countries.
A completely different trigger for innovation comes from the need to reduce the pollution in the world and save scarce recources, while increasing the world standard of living and doubling the world population. This requires a new design and engineering philosophy, which is based on durability. A longer lifespan of ships, extensive re-use of ships parts, emission reduction, improved fuel efficiency, etc. are all necessary to achieve this.

Name ship	Year of built	GT	DWT.	TEU	DWT/GT	TEU/GT
Hannover Expres	1991	58,783	64,500	4,409	1.10	0.075
Min He	1989	37,143	41,175	2,761	1.11	0.074
Bonn Express	1989	29,940	36,000	2,291	1.20	0.077
Ever Gleeful	1988	46,551	53,274	3,428	1.14	0.074
President Adams	1988	61,926	54,500	4,300	0.88	0.070
Hyundai Commander	1988	39,900	43,517	2,641	1.09	0.066
Oriental Friendship	1987	41,664	45,763	3,218	1.10	0.077
Min Promotion	1987	40,446	40,856	3,090	1.01	0.076
Ever Given	1986	40,703	44,425	2,940	1.09	0.072
Alligator Fortune	1986	39,284	40,597	25,12	1.03	0.064
Asian Venture	1984	31,714	36,021	1,960	1.14	0.062
Ever Gather	1984	37,023	43,401	2,728	1.17	0.074
Average		**42,090**	**45,336**	**3,023**	**1.09**	**0.072**
Nedlloyd Clement	1983	33,405	35,890	2,003	1.07	0.060
Neddloyd Houtman	1977	52,007	49,262	2,714	0.95	0.052
Nedlloyd Dejima	1973	57,327	46,984	2,952	0.82	0.051
Nedlloyd Europa (open top container ship)	*1991*	*44,800*	*46,889*	*3,568*	*0.96*	*0.073*

Table VI: Comparison of conventional container ships and *Nedlloyd Europa*

Technological innovation is more and more directed towards these macro economic, or better world environmental objectives. This new thinking is already visible within some sectors of IMO (Marpol) and is likely to become the leading design principle in the next decades.

The invention and development of laser technology led to many applications in science and business. One such application in the maritime sector, is the development and production of a new navigation instrument. The following example, taken from Van Gunsteren's book *"Management of Industrial R&D"* illustrates the overflow of technologies from a different sector into the maritime sector.

In the mid 1970s, a new generation of high performance navigation instruments based on laser technology was conceived to replace conventional spinning wheel gyroscopes, in which a company was the leading firm at the time. R&D was expended with the result that the design was developed after a few years and several prototypes. This design, which only marginally improved the conventional product, was put into production at the beginning of the 1980s.
Poor communication existed between the R&D group and the manufacturing department. This was compounded by a physical distance of over 5000

kilometres between the design authority resident with the engineering department and the manufacturing department. As a result, in the first eight years of production, the product yield (that is: percentage of units that met the design specifications and could be shipped) was never above 65 percent and quite often as low as 30 percent for the monthly period. Money was lost on production of the instrument.
As well, this new generation product consistently underperformed the original product despite the theoretical advantages that it should have had. A large part of the reason that this situation existed, was that the conventional product was still very profitable; it still had higher production volumes and consequently received more management attention.
After a period of time, around 1987, a crisis started to develop. A major competitor displaced the company as the leading firm in inertial gyroscope based systems with laser gyroscopes. The improvements that the competition had made in their laser technology eroded the original firm's position in conventional gyroscopes. With the end of the 'cash cow' phase in the product's life cycle in sight and the weak position in the replacement laser technology, extreme attention was directed by management to the product.
Many design improvements were made, with the active participation of manufacturing and R&D over a short period of three years. This cooperative spirit, almost ten years after initial introduction, resulted in a design that obtained a manufacturing yield in excess of 95 percent per average product that usually met revised design specifications. This was better than both the conventional product and the competitions's laser gyro product. Production costs were reduced to about half the costs per unit that were incurred in the first eight years of production.

A review of the improved design showed that most of the improved features could have been available with adequate development when the product was introduced in the first time. This new product took a decade and probably cost ten times more than could have been achieved with an effective development-production transition. The final result is that this firm is now stuck in the number two position in inertial navigation systems after having had all the advantages and potential of its previous number one position.

This example can be illustrated in terms of the S-curve of technological progress (**Figure 29**). The S-curve of the development of the laser gyro technology did not gain parity with the conventional product. It took a major crisis, induced by a competitor, eight years later, in order to finish adequate development.

7.3.6 Design concept triggers

This book started out with the development in ship design methodologies. With hindsight it is possible to place these methodologies on a S-curve (**Figure 30**). The strength of a concept is measured in its ability to improve the innovative

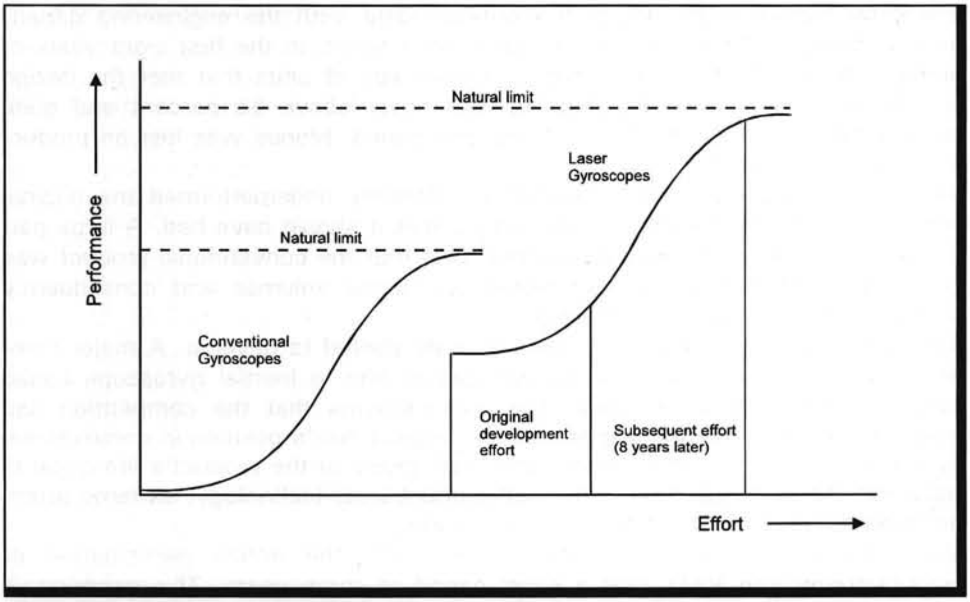


Figure 29: S-curve model of the laser gyroscope

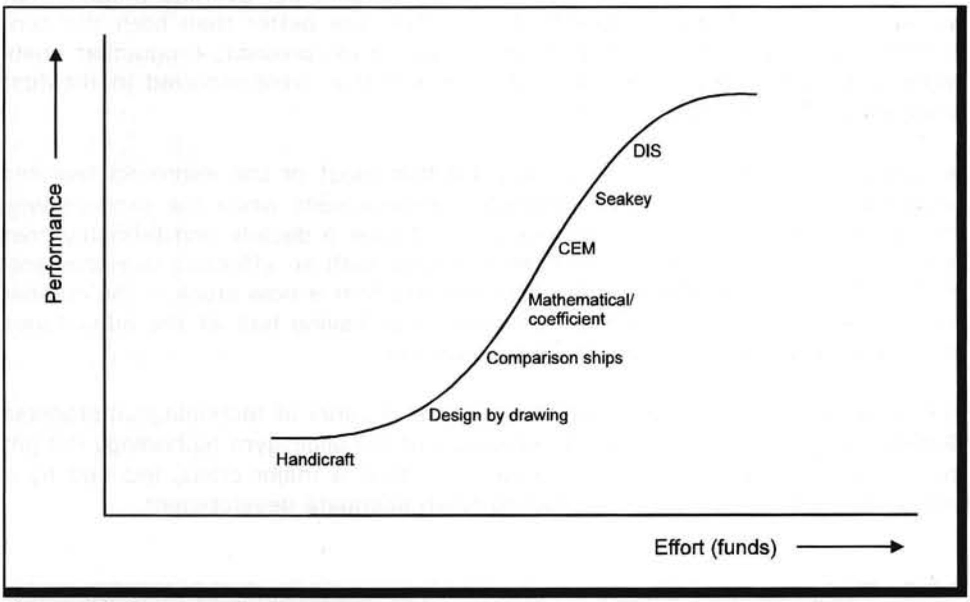


Figure 30:S-curve of ship design methodologies

design methodology, the designer remains within the narrow path of past concepts. This can be useful if one looks for improvement innovations.

The mathematical model methodology and coefficient methodology are actually only extensions of the comparison ship approach. The CEM design methodology forms a minor step in the innovative direction, as only (many) variations of basic design parameters are considered. Basic innovation is sought in the Seakey-design approach. This method seeks to incorporate explicitly the creative search for new concepts. The only limitation is that looking for innovative ship concepts has to start somewhere. But where to start? This depends in the Seakey approach to a large extent on the individual, creative qualities of the designer. The challenge is now to develop a structured design approach in which the innovation framework is explicitly developed as an integral part of the design process. This integrated, structured design innovation method is based on performance indicator analysis, in absolute and relative terms.
The basic idea behind the new methodology is that before the designer (or group of designers) starts out with new ship concepts, they should do first the unglamourous work of performance measuring and drawing S-curves, accompanied by defining limits for each performance indicator. Thus a matrix with performance indicators and limits is constructed, which could look like the one in **Table VII**.

Each performance limit holds a trigger for innovation. Explicitly addressing all these triggers with the help of creativity techniques, creates a springboard for innovation. In fact, it is a systematic way to find many starting points for the design spiral as discussed in **Chapter 3**.
Design innovation in shipping through the use of performance triggers does not throw away the existing design methods, but rather provides a framework for a systematic design approach. Creativity, which is a basic ingredient for innovation, is merged with the traditional engineering approach to design. This allows the designer to loosen up and and be more creative and productive.

	Contraint/limit trigger	Examples
1	**Physical laws**	Resistance in water and waves can be reduced via slender hulls, dynamic lift, powered lift and increasing the speed.
2	**Geographical conditions**	(Air/water) draught, length, width, ice restrictions can be solved with shallow draught ships, waterjet propulsion, split ships, tug barges; ice class.
3	**Economic parameters**	
3A	Revenue maximisation	Combination carriers, in bulkship (COB), or passenger/freight ferries
3B	Economy of scale	Specialisation (chemicals, gas, reefer, etc.) and increase in size, create economies of scale
3C	Capital cost reduction	Simpler designs, lower steel or labour content Creative financing
3D	Running cost reduction	Operational automation of vessel on board ship, at sea or in port (vessel traffic systems)
3E	Voyage cost reduction	Less fuel consumption and reduction of port/canal dues, comparable with other modes of transport
3F	Cargo handling cost reduction	Automated loading and unloading equipment. especially dry bulk and unit load systems will have large impacts
4	**Regulations and other triggers**	Environmental rules and regulations will be much more strict for shipping, which will lead to the development of ships as closed systems, reductions of noxious emissions, reduction of slops, design for durability in order to safe scarce resources; improve safety of ships, via VTS as in the air line industry

Table VII: Matrix with performance indicators

CHAPTER 8: BENCHMARKING IN SHIPPING

The S-curve analysis leads us to the assessment of the limits of a certain technology, as has been demonstrated before. This S-curve represents the absolute measure of the performance of a certain technology. However, in many competitive situations, it is not only relevant to know the absolute limits, but also to know the *relative* performance, relative to the competition. In the short and medium term this is what counts for a firm.
Therefore a different concept is introduced, which measures the relative performance of technologies compared to other technologies. This process involves the continuous search for and application of significantly better practices within the firm. Ultimately this process, which is called *benchmarking*, leads to superior competitive performance. The practices that lead to exceptional performance are called *enablers*.
In this chapter, the benchmarking process will be discussed, as it is a powerful tool to understand and create competitive advantage, and it is a strong stimulus for innovation. In **Chapter 13**, the operational aspects of the benchmarking design methodology and examples will be discussed.

A part of the benchmarking process is the assessment of the level of technology used by the firm and its competitors. Technology Assessment techniques, like S-curves are powerful tools for finding triggers for innovation.

This discussion will lead us to the framework in which benchmarking can be used, the firm structure or business system. Looking at individual products and processes that lead to innovation and competitive advantage, it will become clear that these are part of a well organised environment. Many companies cannot really implement the benchmarking process, because its structure prohibits this. Therefore, management scientists have defined a new concept to restructure or re-engineer the business: Business Re-engineering or Business Systems Engineering. This will be discussed in **Chapter 12**.

This chapter will end with two case-studies on benchmarking in shipping, applied to the Panamax bulk carrier charter market, and the container ship charter market. In these case-studies, it is attempted to define performance indicators, and to measure *relative* performance of ships.

8.1 Benchmarking process

G.E. Watson in *"Strategic Benchmarking"* describes benchmarking as a four-step approach that resembles the Deming cycle: plan, do, check and act (**Figure 1**). In the first step, planning the benchmarking study, it is necessary to select and define the process that is to be studied; identify the measures of process performance; evaluate one's own capability at this process; and determine what companies should be studied. According to Watson, benchmarking has evolved to a fourth generation in its development as a business process.

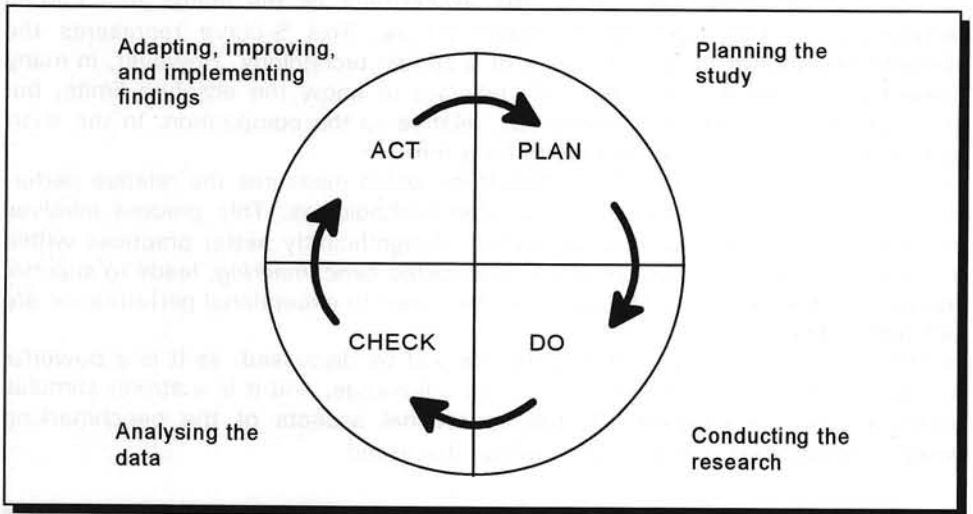


Figure 1: Benchmarking process compared with the deming cycle

As shown in **Figure 2**, the *first generation* of the benchmarking technology may be construed as product-oriented *reverse engineering* or competitive product analysis. In this first generation, comparisons of product characteristics, functionality and performance were made with similar products or services from competitors. Reverse engineering, which tends to be a technical, engineering-based approach to product comparisons, includes tear-down and evaluation of technical product characteristics.

In contrast, the *second generation, competitive product analysis* compares market-oriented features to evaluate the relative capabilities of the competitive product offerings. These methods are in use in most companies, and it moved beyond product-oriented comparisons to include comparisons of processes with those of competitors.

The *third generation* of benchmarking, *process benchmarking*, was developed during 1982-1988, as more quality leaders recognised that they could learn more easily from companies outside their industry than from competitive studies. Companies that compete have natural boundaries beyond which they will not share process information. These boundaries and restrictions do not apply for companies that are not direct competitors. This leads to a broadened benchmarking: Instead of targeting only competitors, they target companies with recognised strong practices independent of the industry. However, this

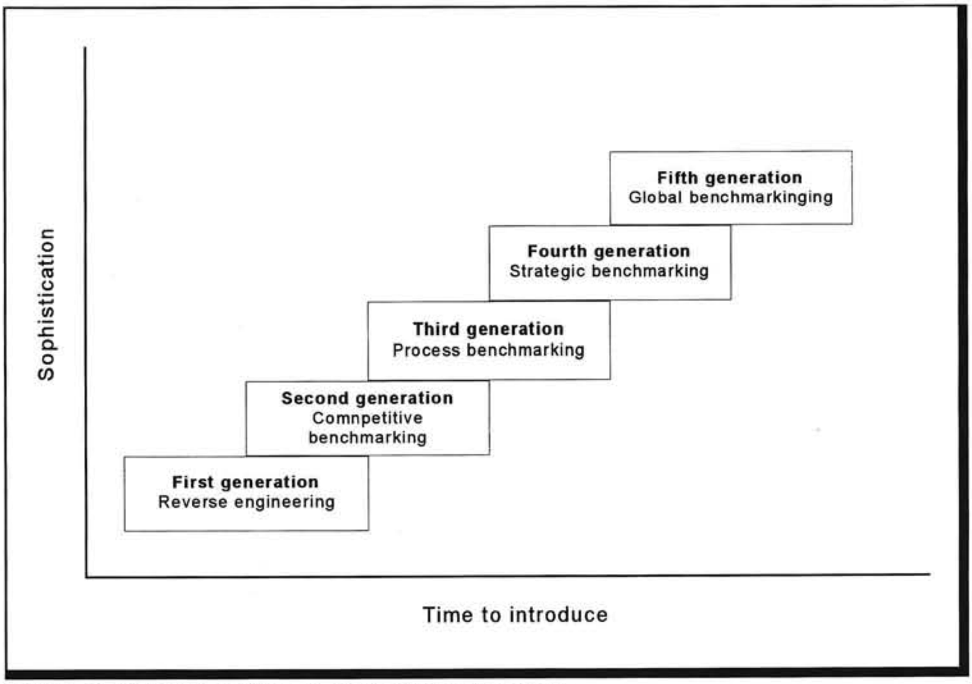


Figure 2: Benchmarking as a developing science

shift also required more in-depth knowledge of the similarities among businesses that may appear greatly different on the surface, in order to understand how to apply lessons learned across these industry boundaries. Such process benchmarking is based on the development of analogies between the business processes at two or more companies.

The *fourth generation* of benchmarking is *strategic benchmarking*, which is a systematic process for evaluating alternatives, implementing strategies, and improving performance by understanding and adapting successful strategies from external partners who participate in an ongoing business alliance. Strategic benchmarking differs from process benchmarking in terms of scope and depth of commitment among sharing companies.

Watson sees a *fifth generation* of benchmarking emerging, which lies in the global application where international trade, cultural, and business process distinctions among companies are bridged and their applications for business process improvement are understood.

The benchmarking methodology will further discussed in **Chapter 13**.

Reverse Engineering

The first generation benchmarking, reverse engineering, is defined in K.A. Ingle's book *"Reverse Engineering"* as a four-stage process in the development of technical data to support the efficient use of capital resources and to increase productivity. The stages are data evaluation, data generation, design verification and design implementation. This process is typically applied for the improvement of production lines or manufacturing capabilities. Ideally, groupings of parts by system or subsystem produce the best pool of candidates for reverse engineering. **Figure 3** illustrates the difference between the traditional design process and the reverse engineering process.

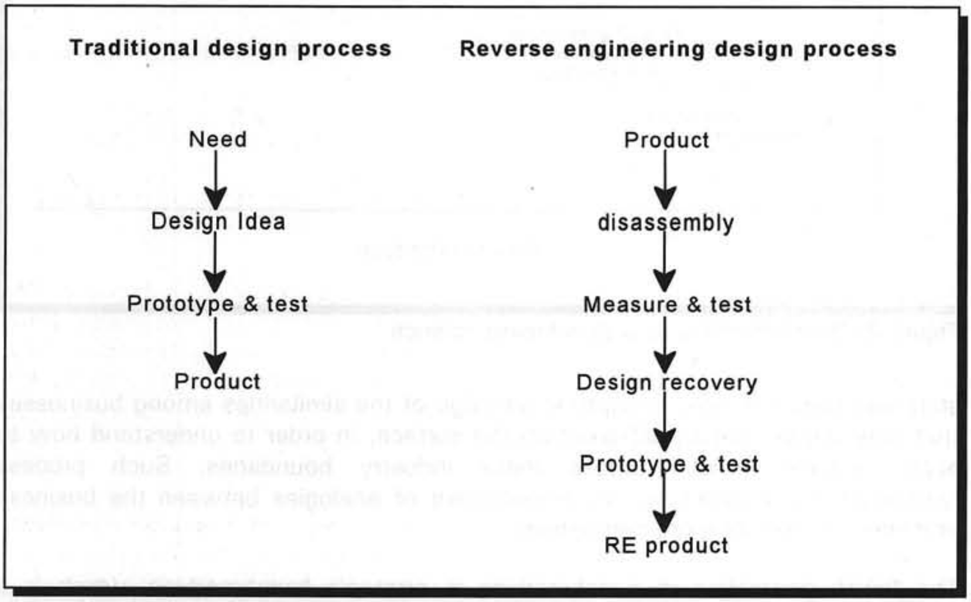


Figure 3: Traditional versus reverse engineering design process

If *forward engineering* is the traditional process of moving from high-level concepts and abstractions to the logical, implementation-independent design needed in a physical system, then reverse engineering is the design analysis of the system components and their interrelationships within the higher-level discrete system. The goal of reverse engineering, then, is increasing the manufacturability and improve documentation by uncovering the underlying design. This design maximisation process is a form of *value engineering* (which in turn is based on value analysis).

8.2 Bulk carrier design benchmarking (internal benchmarking)

Performance indicators used in the benchmarking process of a ship design are the safety standards. In an article in Lloyd's List (12.5.95), Donald Liu from ABS pleaded with the IMO for an urgent review of bulk carrier design safety standards. Many bulk carriers have been lost because of structural damage. He pleads for:

- A re-evaluation of existing safety margins to allow for dynamic loading and damaged strength and stability;
- The design of all new bulk carriers should be analysed using finite element methods;
- Particular attention should be addressed to the critical areas of cargo hold side frames, transverse corrugated bulkheads, cross deck structures and hatch covers and bow structures;
- New concepts should be explored to improve bulk carriers designs;
- Measures should be implemented to ensure that excessive shear forces are not created during loading and discharge;
- A system of rigorous annual inspections of forward cargo hold side frame and hatch covers should be introduced.

ABS makes at the same time a plea for the introduction of a double hull bulk carrier design (**Figure 4**), which has many advantages. The estimated steel weight of this new design is compared (benchmark!) with the current ABS Rules and SafeHull programme for a single and double hull design. The results are shown in **Table I**. The differences are marginal; the extra cost of a capesize double hull bulk carrier over the standard single hull design is US$500,000, and of a Panamax US$250,000.

Vessel size	ABS rules single sided	ABS SafeHull single sided	ABS SafeHull double sided
	Total tonnes	Weight change tonnes (%)	Weight change tonnes (%)
Handymax	4,900	+5 (0.1%)	+160 (3.3%)
Panamax	8,500	+70 (0.8%)	500 (5.9%)
Capesize	18,000	+300 (1.7%)	1,000 (5.6%)

Table I: Estimated steel weight comparisons

This example of comparing designs, is carried one step further in the case-studies on Panamax bulk carriers and smaller (<1500 TEU) container ships.

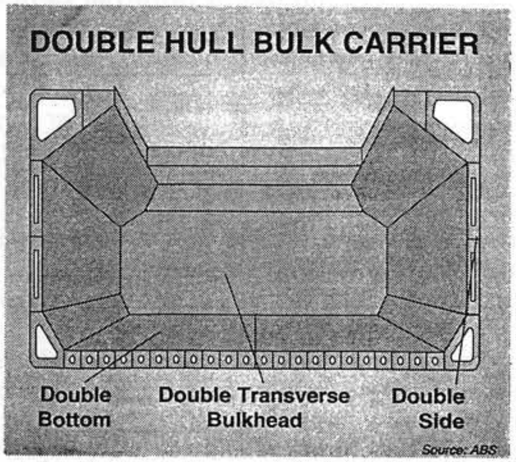


Figure 4: Double hull bulk carrier

8.3 Tanker design benchmarking

In 1992 the I.M.O. issued the MARPOL 73/78 Annex I Regulation 13F for newly built ships. The development of new vessels types, such as double-hull tanker and mid-deck tankers, has to take Regulation 13F into consideration.

World-Wide Shipping Agency (S) Pte. Ltd., of Singapore and NKK Corp. of Japan cooperated in the development of a double-hull tanker design, called the *double-hull void tanker design*. Beside oil pollution prevention, they also considered easy maintenance and hull corrosion protection. The following is an outline of the double-hull void concepts.

Figure 5 (1) illustrates the conventional double-hull tanker design, which, as required by Regulation 13F of MARPOL Annex I, calls for double-hull construction at the sides and bottom of the vessel. These areas are then used as ballast space. The double-hull design has several disadvantages:

- Inspection of the double-hull ballast tanks is difficult, becuase of the boundary areas between cargo oil tanks and the ballast water tanks as well as those between the sea and the water ballast tanks. The humid dark and slippery conditions in the double-hull ballast space add further obstacles to inspection procedure;
- The configuration of the double-hull ballast space hampers cleanup of oil leaks into the area and dirt accumulated in the double-bottom ballast space;

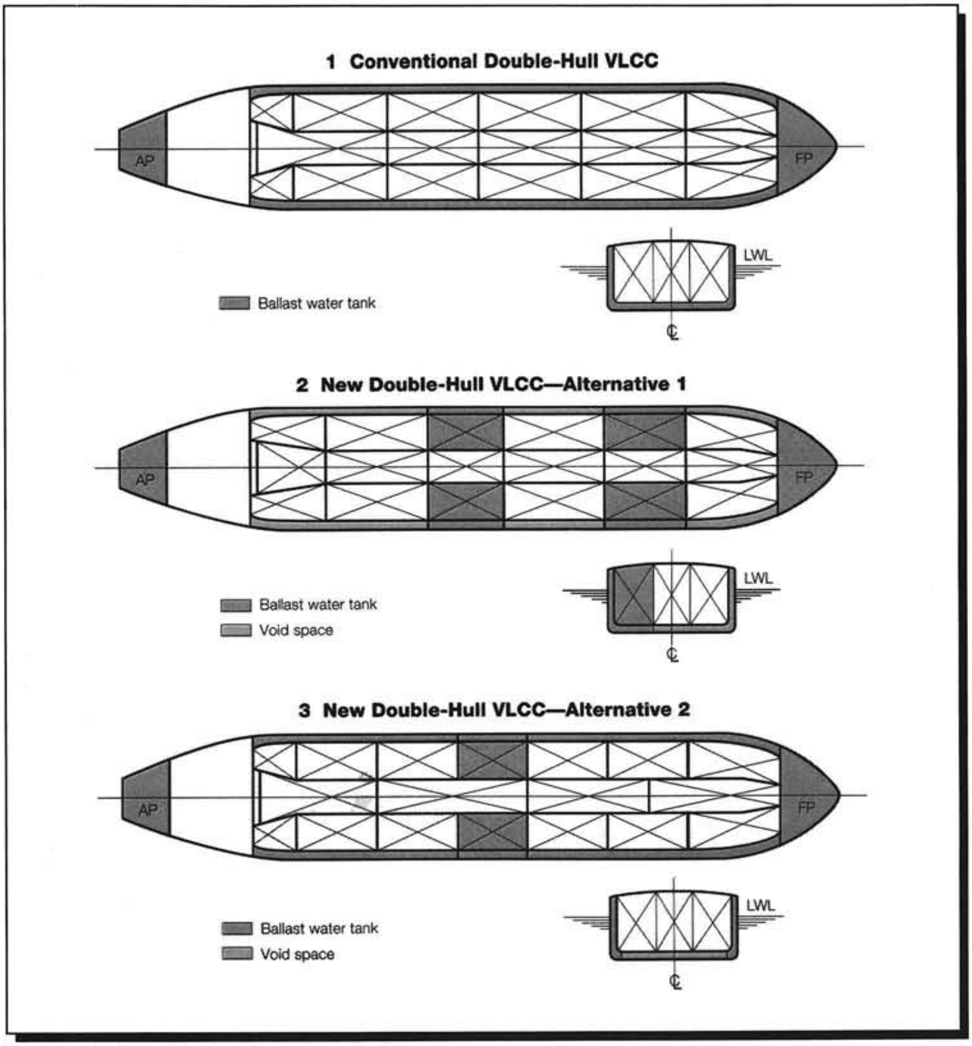


Figure 5: Double-hull tanker designs

- The structural complexity of the double-hull space interferes with gas freeing and ventilation, necessary before inspection and maintenance operations;
- The mandatory lengthwise and evenly distributed arrangement of cargo oil tanks and ballast water tanks in conventional double-hull tankers causes a higher hull-girder bending moment than that seen for single-hull tankers, in both loaded and ballast conditions;

- The coated area in conventional double-hull ballast spaces is similar to that of single-hull tankers. Consequently coating maintenance requires twice the effort and cost, and the risk of coating breakdown is greater.

The new design concept combines the design merits of single and double-hull tankers, eliminating many of the problems inherent in conventional double-hull tankers. Two alternative features have been proposed in the new design.
The first recommend is that all double-hull spaces have to be dry and void. Ballast water is carried by two pairs of permanent wing ballast tanks as well as a fore peak tank and aft peak tank as shown in **Figure 5** (2). The second alternative (3) has a dry and void double-bottom space. The side double-hull spaces are used as ballast spaces in combination with one pair of permanent wing ballast tanks and fore peak and aft peak tanks.

The new double-hull design has the following advantages:

- The double-hull space is coated with an appropriate light-colored paint. Little corrosion is expected here since it is not used for ballast purposes.
- Since the coating area for ballast spaces in the first alternative is about half that of the conventional double-hull design, coating maintenance costs will be lower.
- The dry and light conditions of the void, double-hull spaces will permit easier and safer inspection of these areas.
- The double-hull spaces are dry and equipped with gas detectors. Cargo vapour is more easily detected and readings are therefore more reliable in these dry spaces than obtainable from devices in the double-hull ballast spaces of conventional double-hull tankers. Such reliability removes hazard that may be encountered during preliminary inspections, in such cases as oil leaks from cargo tanks, and expedites cleanup and repairs;
- The still water bending moment of the new double-hull design is lower than that of the conventional double-hull design, due to the fitting of ballast tanks to the cargo oil tank space;
- Since the double-hull spaces are void and not used for ballast purposes, the spaces will be free of sand and dirt.

The new design may solve many of the problems encountered on conventional double-hull tankers. A comparison of the main particulars is given in **Table II**. The size of tankers built to double-hull void design specifications increases to accommodate additional void space. The reason for adding void space is to further reduce the risk of oil pollution in the events of a collision and to enhance safety during navigation and inspection. Extra void space should also lower maintenance costs.

Item	Conventional double-hull VLCC	New VLCC - Alternative 1	New VLCC - Alternative 2
Length (b.p.) Breadth Depth Draught	317.0 m 58.0 m 31.4 m 21.0 m	325.0 m 60.0 m 34.0 m 20.0 m	317.0 m 58.0 m 32.9 m 21.0 m
Gross tonnage Deadweight Capacity of cargo tanks	161,000 tonnes 280,000 tonnes 350,000 m^3	185,000 tonnes 280,000 tonnes 350,000 m^3	167,000 tonnes 280,000 tonnes 350,000 m^3
Weight of hull steel coated are of ballast water tank	100% 100%	110% 55%	103% 75%

Table II: Comparison of conventional double hull VLCC with other alternatives

8.4 Benchmarking Panamax bulk carriers

Panamax bulk carriers constitute the largest homogeneous ship type group in the world fleet. The H. Clarkson database contained in 1994 some 834 of these ships in the deadweight range of 50,000-75,000 dwt.
The dimensions of Panamax vessels are restricted by the dimensions of the locks in the Panama Canal, especially the breadth (32,23m). Shipowners and shipyards have put a lot of effort over the last decades into the maximising of the deadweight of the bulk carrier within these restrictions. This continuous process of improvement innovations is driven by the shipowners and shipyards, which try to create a better performance of the vessel, and consequently make a better return on investment.
The basic question is whether the shipping market honours their efforts? In other words, does the increase in performance lead to higher charter rates? In order to answer these question, it is imperative to define the term 'perfo-rmance'. Which elements of a ship design determine the performance, and how can one measure these parameters?
If an owner wants to compare the performance of his bulk carriers with the industry as a whole, than he has to start a benchmarking project.

In the study *"Analysis of the Panamax Bulk Carrier Charter market 1989-1994, in relation to the Design Characteristics"*, approximately 10,000 published charter fixtures of Panamax bulk carriers covering the period of 1989-1994 have been analysed and the charter rates are related to the design characteristics of the bulk carriers.

This benchmarking project of the Panamax bulk carriers has created important insights in the performances of these vessels. A summary of the *period time charter market* illustrates the benchmarking approach.

8.4.1 Panamax bulk carrier characteristics

The database contains a lot of information about the attributes of the ship. Attributes that may influence the charter price are:

- *Classification Society*
  The most used classification societies are Lloyds Register (189), American Bureau of Shipping (165), Nippon Kaji Kyokei (138), Det Norske Veritas (138) and Bureau Veritas (78).

- *Flag State*
  The vessels are registered all over the world. The countries with the most ships are those with a flag of convenience like Cyprus (93), Liberia (90), Panama (83), Malta (46), Phillippines (44), Norway (41, second register). The largest flag state is Greece with 130 vessels.

- *Owner*
  Most vessel are owned by companies. Some are owned by governments. Even a large company has a very limited number of vessels. This means that no single company can influence the market by itself.

- *Builder/Yard*
  The 834 vessels which were analysed, were built between 1969 and 1994. There are/were 100 yards capable of building Panamax bulk carriers. Although most vessels are built in Japan and South Korea, the yard that has built the most is Burmeister & Wain in Copenhagen.

- *Main engine make*
  There are only 8 known producers of engines. The two largest manufacturers are A/S Bürmeister & Wain and Hyunday S.B. & Heavy Industries Ltd.produce 82% of all engines placed in bulk carriers.

- *Age*
  The age is calculated with 1994 as reference year. All vessels were built in 1965 or later. Nearly half of all vessels was built in the periods 1974-1978 and 1981-1983. The average age of the considered vessels is 12.9 year.

- *Deadweight*
  The deadweight ranges from 50,000 up to 76,000 tonne. The largest group lies within the range 60,000-70,000 tonne. It comprises 55% of all

vessels **Figure 6** shows the deadweight as a function of the year of built. Only vessels that are still in operation have been taken into account. As can be seen the deadweight of Panamax vessels has increased significantly since 1984.

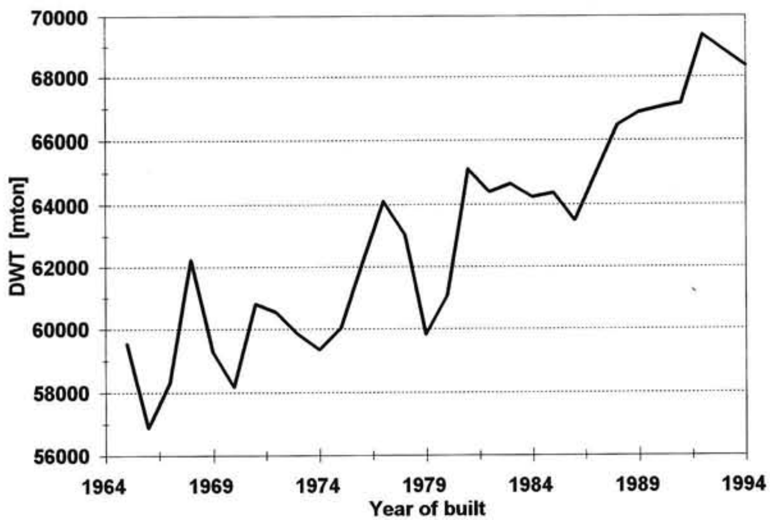


Figure 6: Deadweight as a function of the year of built

- *Service speed*
  The minimum service speed is about 10.5 knots, the maximum about 17.60 knots. The average speed is 14.6 knots. Nearly 75% of all vessels have a trial speed in the range 13.5-15.5 knots. **Figure 7** shows that the average speed of the vessels, built before the second oil-crisis, 1979, was 15 knots. The average speed of the vessels built in the 1980s was about 14 knots. Recently built vessels show that the average trial speed is increasing again to about 15 knots.

- *Heavy fuel oil consumption*
  The fuel consumption determines to a large extent the voyage costs. **Figure 8** shows the fuel consumption as a function of the year of built. It shows clearly that newer ships have better main engines, which consume less oil than older ones.

- *Main dimensions*
  Main dimensions are important, since many canals, locks, harbours and quays, cause restrictions. 90% of the considered vessels has a length less than 225m and nearly 65% has a length in the range between 210 and 220m.

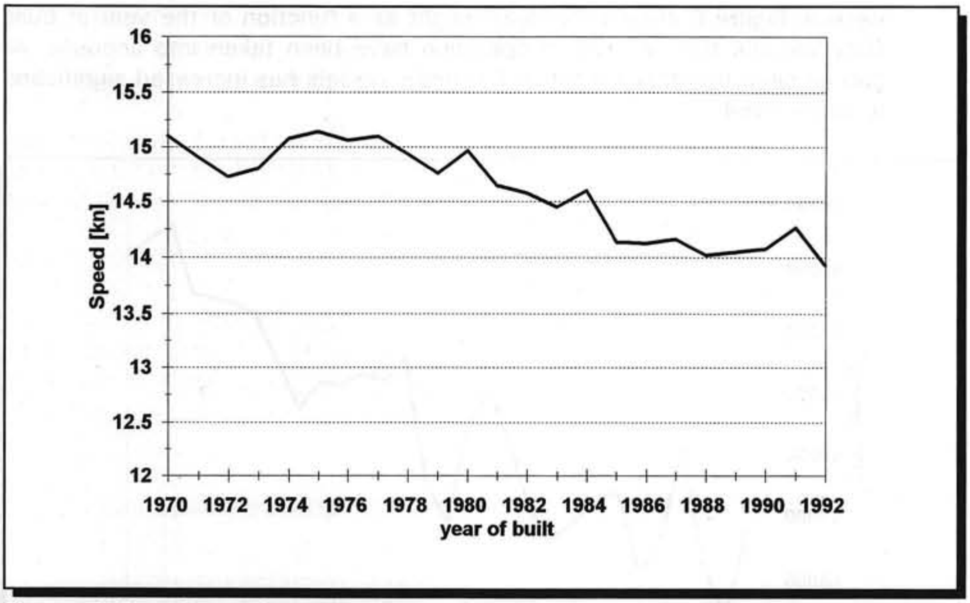


Figure 7: Speed as a function of the year of built

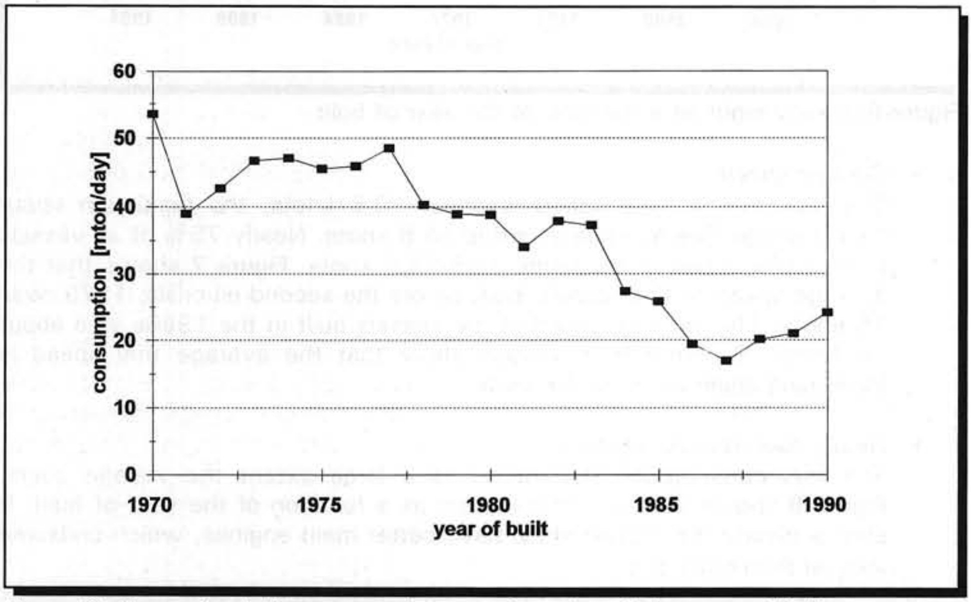


Figure 8: Heavy fuel oil consumption as a function of the year of built

More than 85% of the considered vessels has a width less than 32.20m, the restriction of the locks in the Panama Canal. The smaller vessels are usually older. Twenty-four of the vessels are wider than 32.20 meter and are eliminated from further analysis.
The draught in the Database is the maximum allowable draught. The distribution shows two peaks, each peak representing about 180 vessels. The first peak is at a draught of approximately 12.25 meter, the second one at approximately 13.00 meter.

- *Cargo capacity/grain capacity*
  The minimum grain capacity is 2,011,409 cuft. (56,957 m^3), the maximum grain capacity is 3,115,980 cuft. (88,2345 m^3), the average grain capacity is 2,657,591 cuft (75,255 m^3). The largest group is in the range between 2,600,000 and 2,700,000 cuft.

8.4.2 The charter market

Charters can be divided into three types:

- Period time charters;
- Trip time charters;
- Single voyage charters.

Each type has its own characteristics and its own charter rate. The youngest vessels were built in 1994, the oldest ones in 1972 and are 22 years old. The variance in charter rates is wide. The lowest rate is $2,000/day while the highest rate is over $16,000/day. Of course, these rates will be the same for all following period time charter scatter diagrams. **Figure 9** shows the charter rates as a function of age, for period time charters.

The charter rates of trip time charters show the same behaviour. There is also a wide variance.

It is difficult to compare the mutual single voyage charters because charter rates depend on the products transported. So to examine single voyage charters in a proper way, they should be divided by cargo. It is therefore also difficult to compare them with the other types of charters.

By plotting charter rates against time cycles can be observed. **Figure 10** shows an example for period time charters. To eliminate these business cycles, an index on basis of charter rate is composed for every fixture type .

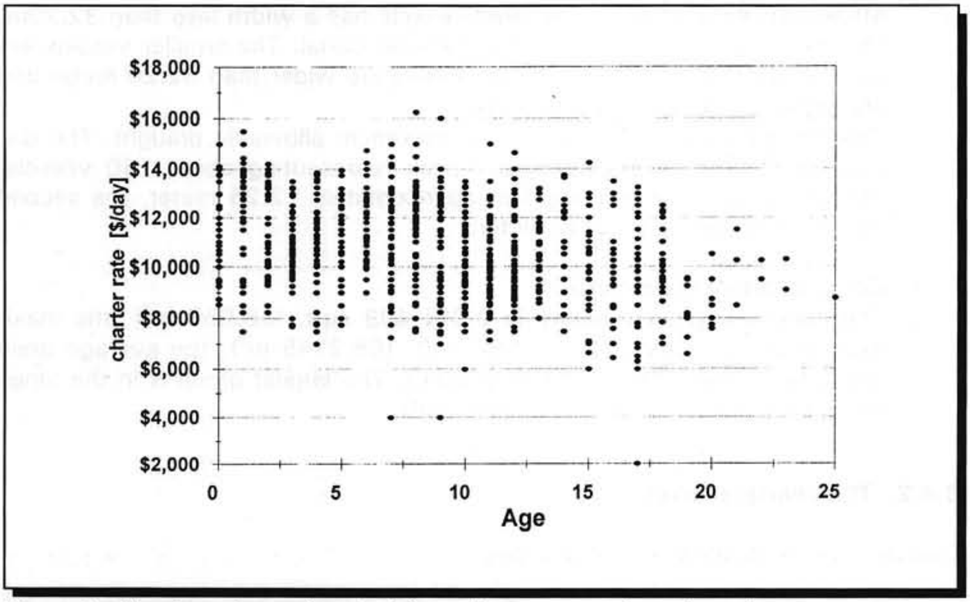


Figure 9: Charter rates of period time charters as a function of age

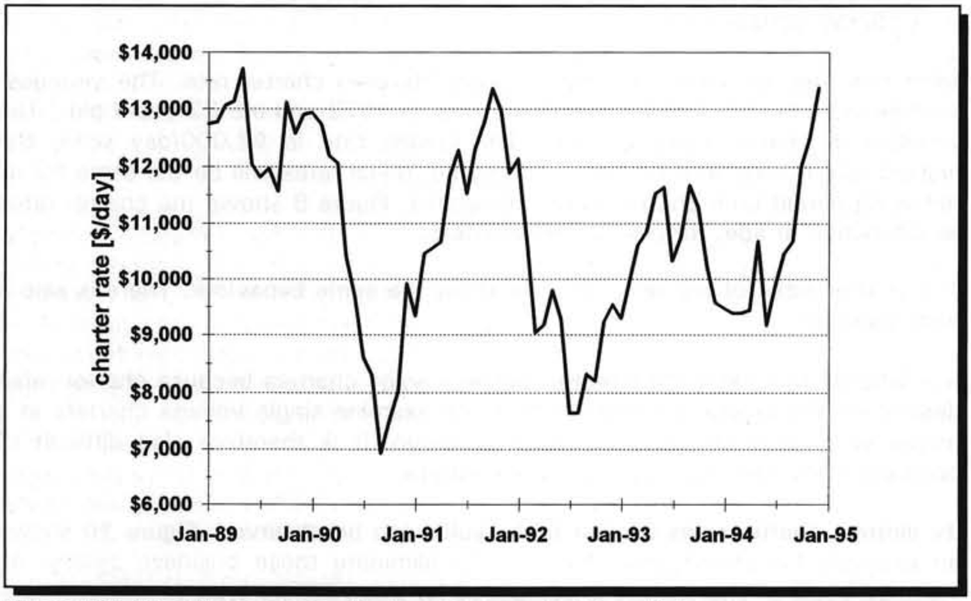


Figure 10: Monthly average charter rates, period time fixtures

For each time interval, each month, the average charter rate is calculated by the following formula:

$$Average\ Freight\ Rate_j = \frac{\Sigma\ Charter\ Rate_{i,j}}{N}$$

Where:

i = 1..N fixtures per time interval
j = 1..m, time interval
N = Total number of fixtures of that time interval

The index is composed according to the following formula:

$$Charter\ Index_i = \frac{Charter\ Rate_{i,j}}{Average\ Charter\ Rate_j} * 100$$

The basic assumption is that in this way the relative performance of the ships is obtained, while the unpredictable 'noise' of the world economy is neutralised. The cycle fluctuation will be filtered out. An index level can be set (in this case set to 100) and the fixtures with the highest deviations can be detected.
To determine which ships to select for a more detailed analysis, boundary levels are determined. These boundary levels may not be too small because too many vessels would be selected, and for a large boundary level, the selected number of ships would be too small. The boundary level has to vary at least 10% from the index level (100), to filter out most of the 'noise' induced by the economic business cycles.

The market is self regulating, regulated by supply and demand for ship's capacity. If demand for ships is high, the charter rates will increase and if demand for ships is low, charter rates will decrease. This is why this market is very efficient. A deviation of 10% is rather high. The average charter rates of all period time fixtures, is about US$10,000/day. Suppose a ship outperforms and gets a 10% higher rate. This means that the ship earns about US$1,000 per day more or on an annual basis 350 * US$1,000 = US$350,000.

For a first selection the boundary levels will be set at 100 plus Standard Deviation for the upper boundary, and 100 minus Standard Deviation for the lower boundary. Or in formula:

$$Upper\ Limit = 100 + \sigma \qquad Upper\ Limit = 100 - \sigma$$

Which causes can be identified as being important for the deviations of the index figures? Possible major causes are:

- Differences of contracts per fixture type;
- Market mechanics;
- Quality of the ship.

Figure 11 shows the period time charter index from 1989 up to and including 1994. The figure shows a narrow range with almost all index figures in it. The width of this range is about 40% of the index level (100). The Standard Deviation is 10.14. The chosen lower limit is 89.86 and the chosen upper limit is 110.14

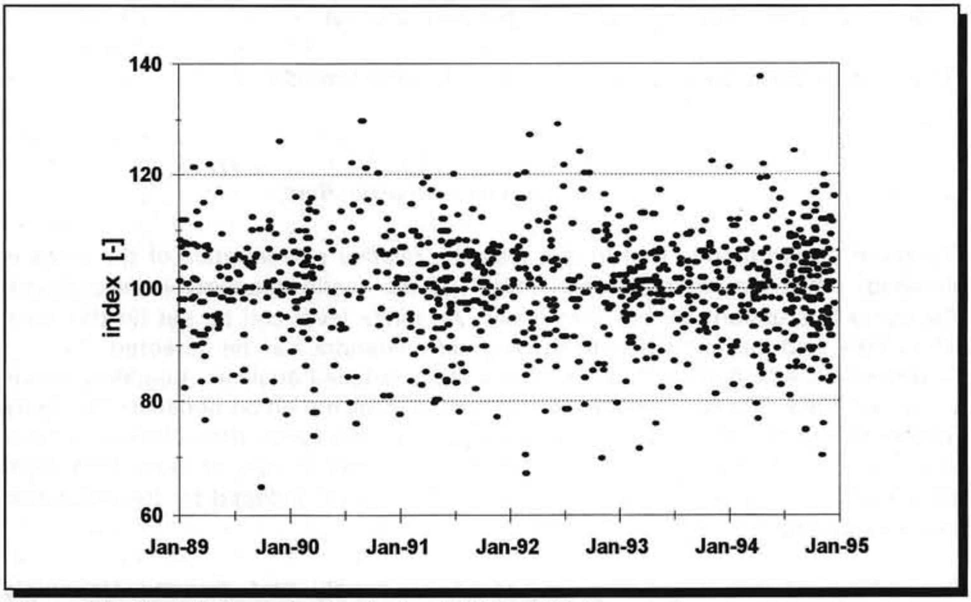


Figure 11: Period time charter index 1989 - 1994

8.4.3 Index analysis

The ship that under- or outperform the market are selected for further analysis. The definitions of under- and outperformce are:

- *Outperformance*
  Ships that occur at least 5 times in the fixture database and with index figures higher than 117.58. The selection is as follows: The percentage of occurrence of the index figures higher than 117.58 has to be at least 75%. This means that if a ship occurs 8 times in the fixture database, the number of times it outperforms is at least 6.

- *Underperformance*
  This selection criteria selects ships with index figures less than 82.42. These ships have to be in the list at least 5 times, and the percentage of occurrence lower than 82.42 has to be at least to 75% of the total occurrence.

This section tries to analyse why the selected ships have a better performance record than the other, not selected ships, the ultimate purpose of this analysis.

This is done by examining tables, indicating design or fixture characteristics and several statistical data like the number of occurrences, average charter rates, average index figures and average ages. On this basis, scatter diagrams are made in which the index figures are plotted against design characteristics.

The selected outperforming ships consist of 32 bulk carriers while the underperforming ships form a group of 19 bulk carriers. This brings the total number of selected ships to 51 bulk carriers which were analysed more closely. These 51 selected ships made, in the years 1989 up to and including 1994, 316 fixtures.

Classification Society
The largest classification society is Lloyds Register. This goes for both the selected outperforming as well as for the selected underperforming ships. With a total of 19 ships, this is nearly 25% of all selected ships. No conclusions can be drawn on basis of the classification society.

Flag State
From all selected outperforming ships, a majority is registered in Greece. Of the selected 32 ships, 19 ships are registered in Greece. The average of the index figures is 120.93. Also the majority of the underperforming ship is registered in Greece.
The main difference between both categories is average age of the ships. The average age of the outperforming ships is less than 8 years while the average age of the underperforming ships is about 17 years, so twice as old.

Owner
The 51 selected ships are owned by 41 owners. The difference in average age is obvious again although not as obvious as for the other items. The average age of the ships of the Livanos Group is 10 years while the average age of the ships of Metrofin Ltd. is 10 years as well.

Builder/Shipyard
The selected 51 ships are built at 30 different yards. There exists a large gap between the average ages of the outperforming ships and the underperforming ships. No conclusions can be drawn from this.

Main engine make

From the selected 51 ships, 22 ships are provided with a Sulzer engine and 20 with a B&W engine, together their market share in the Panamax bulk fleet is over 80%. B. & W. has 16 out of the 20 (75%) entries in the table of the out-performing ships, Sulzer only 12 out of the 22 (just over 50%).

Age

Old ships get a lower index figure, which means that they get a lower charter rate than the average of that month. Of all trip time fixtures the average charter rates and the average index figures have been calculated for each age from 0 to 20 years. **Figure 12** shows that new ships get the highest average charter rates. The first 5 years, ships get an average charter rate of about US$11,750/day. Ships with an age from 5 to about 14 years get an average charter rate of about US$10,500/day. Ships older than 14 years get an even lower charter rate.

For every extra year of age, the average chater rate of the ship decreases by approximately US$500/day. The difference in charter rate of a new ship (say 2 years old) and an old ship (say 18 years old) is about US$3,402/day. On an annual basis this is about US$1.2 million.

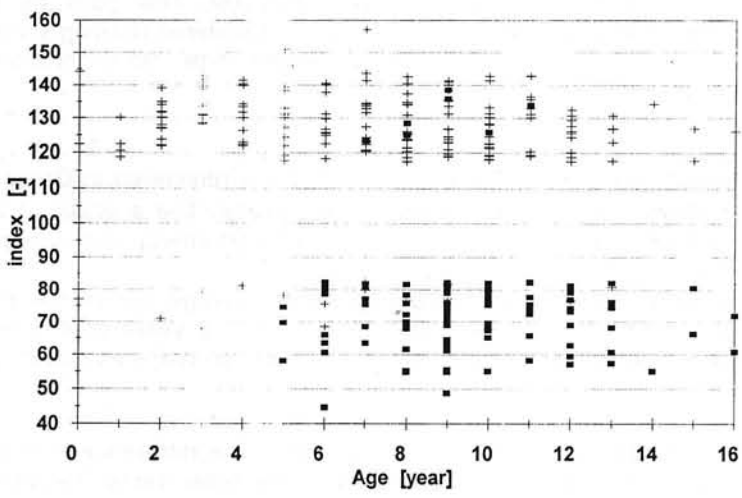


Figure 12: Age vs. average charter rate and average charter index

Deadweight

Underperforming and outperforming ships are in the same deadweight range. A group is in the range of 50,000 to 55,000 dwt and another group is in the

60,000 to 67,000 dwt range. This indicates that there is no particular deadweight range that gets systematically higher charter rates.

Sailing speed
The sailing speed used her is the speed as mentioned in the fixtures. The speed ranges from 12 up to 14.5 knots, independent of the index figure. Most fixtures have a sailing speed of 13 knots. These fixtures have an average age of about 12 years. Ships with a sailing speed of 13.5 or 14 knots are newer ships, which shows in the average charter rates and in the average index as well. Ships with a sailing speed of 13.5 knots earn about US$1,000/day more than ships with a sailing speed of 13.0 knots. The average index of the faster ships is about 10 points higher.

Heavy fuel oil consumption
The HFO consumption determines, to a large extent, the voyage costs. These voyage costs are paid for by the charterer. This means that if a ship has a high HFO consumption the charterer will try to get another ship. If this is not possible the charterer will try to get a lower charter rate as compensation for the high consumption. So ships with a high consumption have a low index figure.

Main dimensions
Most selected ships have the same length as all the other ships in the database. The same goes for the draught.

Grain capacity
Most Panamax bulk carrier have a grain capacity of around 2.6 mln cuft. with a small peak at 2.8 mln cuft. Most selected vessels have a grain capacity of around 2.6 mln cuft. Just as the underperforming vessels, it seems that the ships with a smaller capacity get lower charter rates and vise versa.

Other attributes

<u>Strengthened for ore</u>
From all considered 51 ships, 28 ships are strengthened for ore (of which 12 ships outperform the market and 16 underperform the market), 2 ships cannot carry ore and for the other 21 ships it is not known.

<u>Strength for heavy cargo</u>
From the considered 51 ships, 17 are strengthened to carry heavy cargoes, one ships cannot carry heavy cargoes, and for the 33 others it is not known. Of the 17 ships which are strengthened to carry heavy cargo, 15 ships are outperforming the market. The average charter rate is US$12,693/day with an average charter index of 122.74. The average age of these 15 ships is 7 years.

Ice-class
From the 51 selected ships, only one ship can sail through ice, 4 cannot sail through ice, while for the remaining 46 ships it is not known whether these ships are able to sail through ice. These are not enough data to draw any conclusions.

Geared vs. gearless
From the total of 51 ships, 9 vessels (8 outperform the market and 1 underperforms the market) are not geared while only one ship is provided with some kind of loading and/or discharging gear. It is not known whether the other ships are provided with gear to load and/or discharges its cargo. Since only one ship is registered to have gear, it is not possible to speak of a trend that geared ships earn higher charter rates than gearless ships.

8.4.4 Conclusions

The fuel consumption effects the charter rate indirectly. If a charterer is able to choose from two ships with as the only difference the fuel consumption, he will charter the one with the lowest fuel consumption.
But this situation hardly ever occurs. Generally, more differences between the ships occur, like a combination of differences as in deadweight, age and fuel consumption. There exists a relation between the fuel consumption and the age of the vessel. Newer ships have, usually, a lower fuel consumption. Charterers pay a lower charter rate to for older vessels compensate the higher fuel consumption of the chartered vessel.

The fuel consumption will determine the total costs of the transport though this differs per fixture type. For a time charter the fuel costs are to be paid by the charterer while the fuel costs for voyage charter are to be paid by the shipowner.

The amount of fuel consumed by the engine is determined by the required power. The required power is determined by the required speed. The relation between power at speed is:

$$Power \cong f(v^3)$$

Increasing the speed with one knot, which is an increase of about 8%, can result in an increase of fuel consumption of about 5 tonnes per day, which is an increase of about 16% if the fuel consumption is 30 tonnes per day at the low speed.

A firm market will increase the ship's speed in order to capatalise on the high charter rates in the hope that the additional costs, incurred in bunker costs will be compensated by the extra trade generated and time saved. In a soft market the owners will decrease the speed again for the opposite result.

The age in relation to the fuel consumption of the ships determines the height of the charter rates. This is shown in **Figure 13**. Another way to state this, is that some operators like Shipmair, who use old ships, pay lower charter rates. The average age of the chartered vessels by Shipmair is over 15 years. Old ships which have been depreciated have low capital cost and no interest costs. This could mean that the owner can decrease the charter rates, since costs are lower.

Another reason to pay a lower charter rate is the high fuel consumption of the old ships. According to **Figure 13**, which shows the average fuel consumptions plotted against the building year, old ships use more fuel oil than new ships. In the same figure the average charter rate has been plotted against the building year. The line shows clearly that new ships get higher charter rates than old ships. The total costs of a trip have been calculated the following way:

$$\textit{Total costs} = \textit{Charter rate} + \textit{Fuel costs}$$

with

$$\textit{Fuel costs} = \textit{Fuel consumption} * \textit{Fuel price}$$

The sailing time of these ships is estimated as 70% of the total time, the other 30% the ship will be in a port, loading or discharging. The total costs are for ***all ships*** about US$13,000 per day. So it does not matter whether one charters an old ship with high fuel costs or a new ship with low fuel costs. The total costs are about the same. This is due to the total transparency of the bulk carrier charter market. Over 400 shipowners and over 500 charterers are playing a role in this market. And even the large owners or large charterers can hardly influence the charter rates. Although some charterers can get lower charter rates than the average but only by good timing. The same is valid for some shipowners.

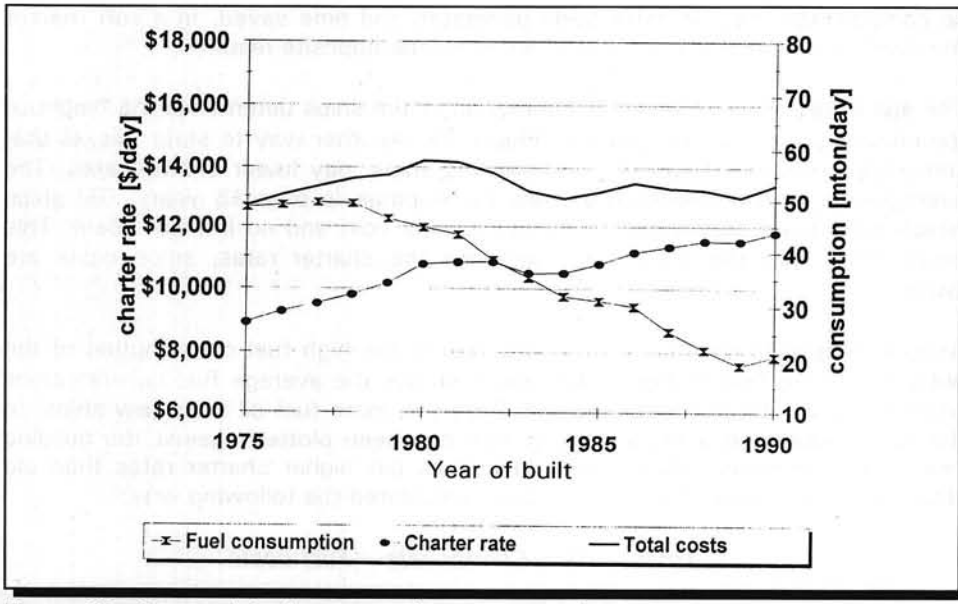


Figure 13: Cost and fuel consumption vs. year of built

8.5 Benchmarking container ships

What is a good container ship? The answer to this question depends to a large extent on the perspective of the person asking it. The answer will be different for the shipowner, naval architect, shipyard, financier, terminal operator, and so on. From the perspective of the shipowner or charterer, the relevant question is: do(es) my ship(s) consistently outperform or underperform the charter market. Ships that operate in a captive service, and not in the open market, do not publish charter rates, and the performance can therefore not be measured by the outside world.
Through an extensive analysis of ten years of charter fixtures (7,000) of container ships, the relative performance of container ships is established. On this basis, it is attempted to explain and relate the charter market performance to the design characteristics of the ships. The results of the benchmarking exercise are published in *"Analysis of the Container Ship Charter Market 1983-1992 in Relation to the Design Characteristics of Container Ships"*, and are summarised in this section.

8.5.1 Container ship design characteristics

Figure 14 shows a scatter diagram of the charter rates in US$ per day as a function of the ship size in TEU. **Figure 15** shows the charter rates in US$ per TEU per day also as a function of the ship size in TEU. The figure shows that the charter rate in US$ per TEU per day depends very much on the size of the ship. For a container ship, TEU capacity is the most important size indication, rather than its deadweight.

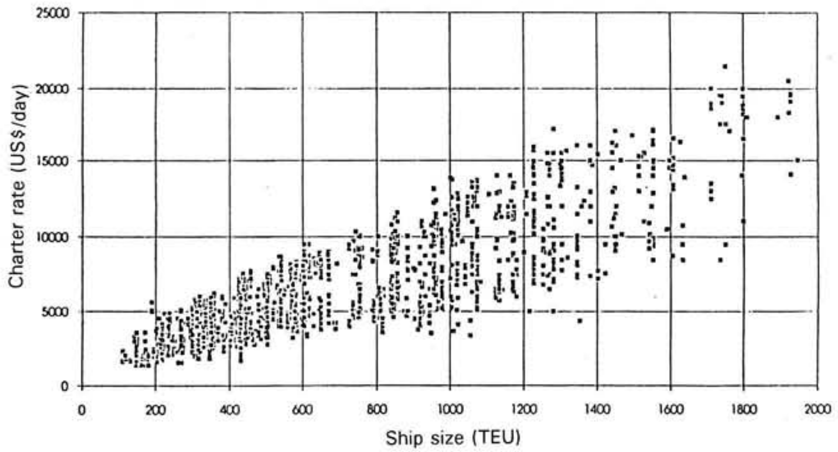


Figure 14: Charter rates in US$ per day as a function of ship size

Deadweight is mainly relevant for charterers on special trades, where the average weight of the containers (in tonne/TEU) is higher than the industry average of 12 tonne. An example of this is the South America - Europe trade, where containers often have an average weight of more than 14 tonne. Deadweight also includes bunkers, so the sailing range may be limited by the deadweight.

As deadweight has a strong relationship to the TEU capacity an increase in deadweight will result in an increase in charter rate. The high variance in the scatter diagrams may be caused by the wide range of trade areas and also the wide variety in speed.

Figure 17 shows a scatter diagram of the dwt/TEU-ratio and the charter rate. The highest earnings are achieved by ships in the range of 13-18 tonne/TEU. **Figure 18** shows the distribution of the number of time charter fixtures and the corresponding dwt/TEU ratio.

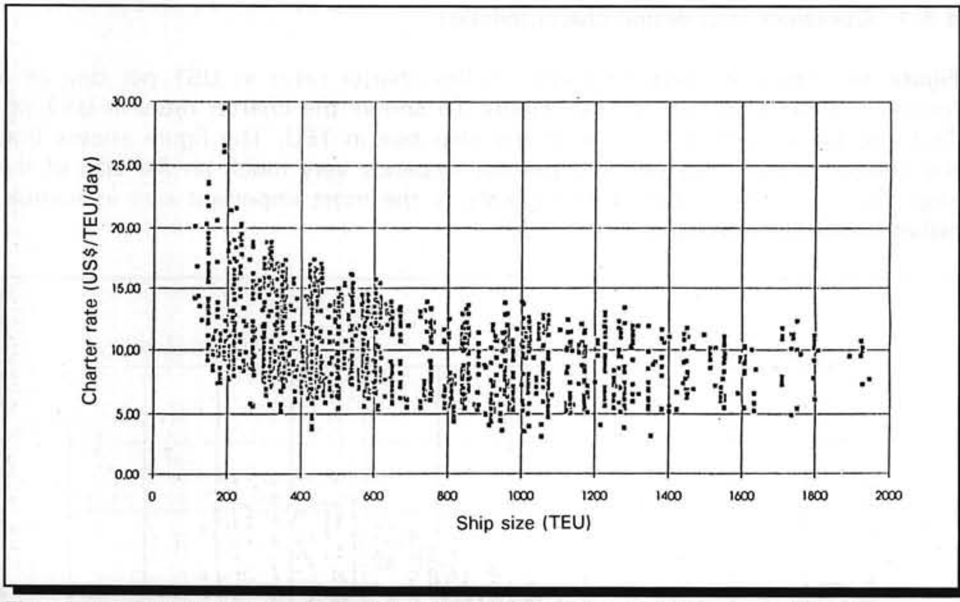


Figure 15: Charter rates in US$ per TEU per day as a function of ship size

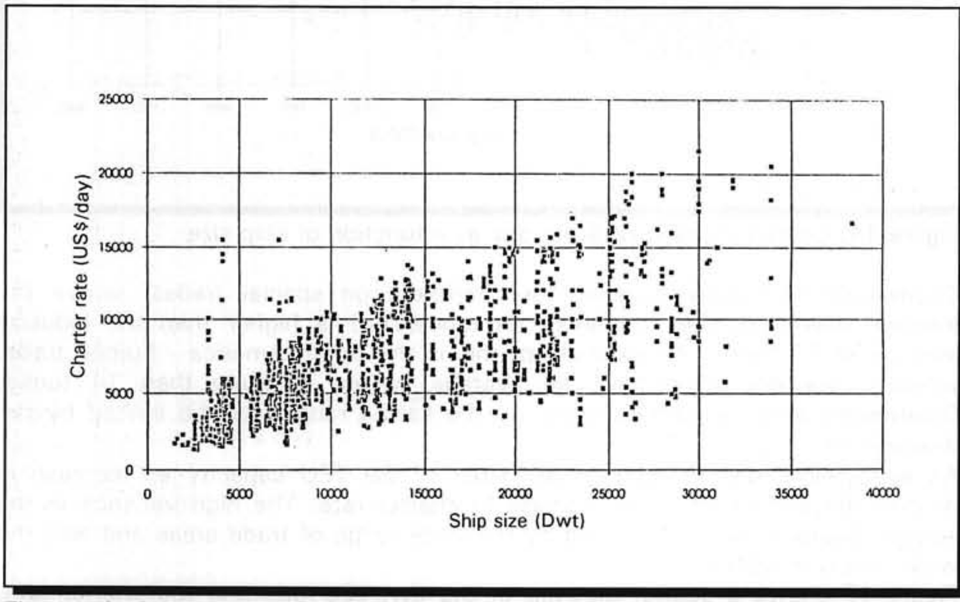


Figure 16: Charter rates in US$ per day as a function of deadweight

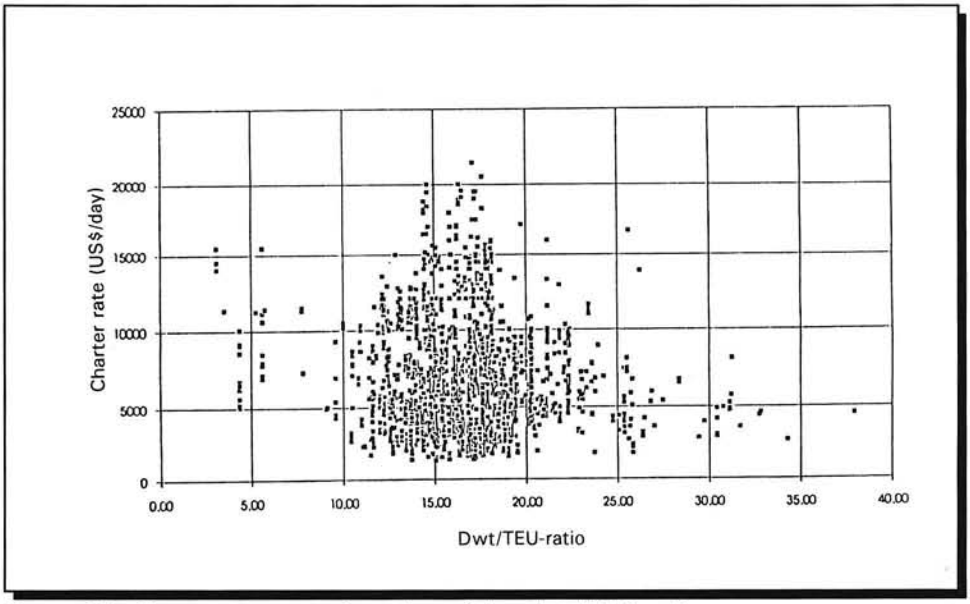


Figure 17: Charter rate as a function of the dwt./TEU-ratio

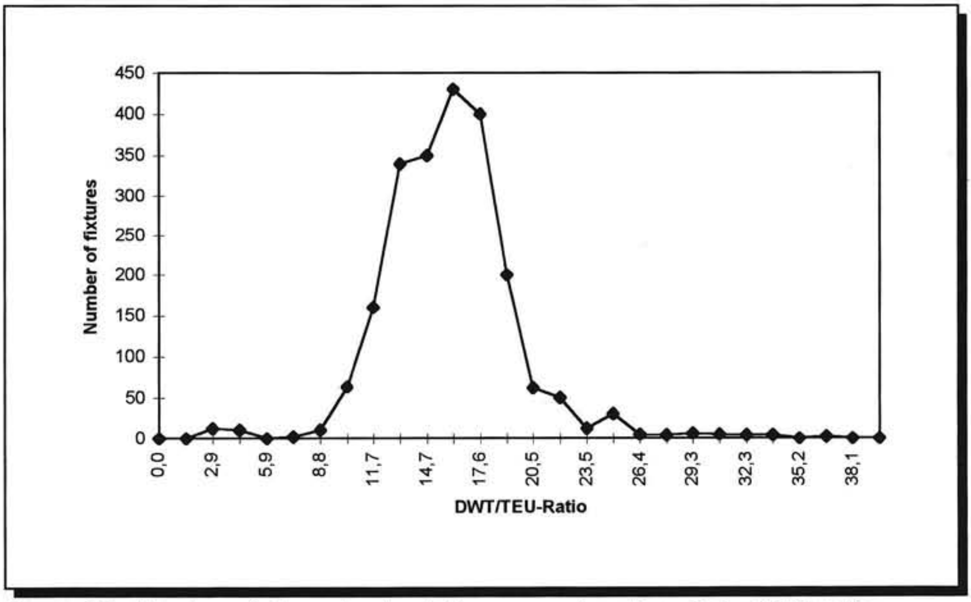


Figure 18: Number of time charter fixtures as a function of dwt/TEU-ratio

Figure 19 and **Figure 20** show the relation between the speed in knots and the charter rate.

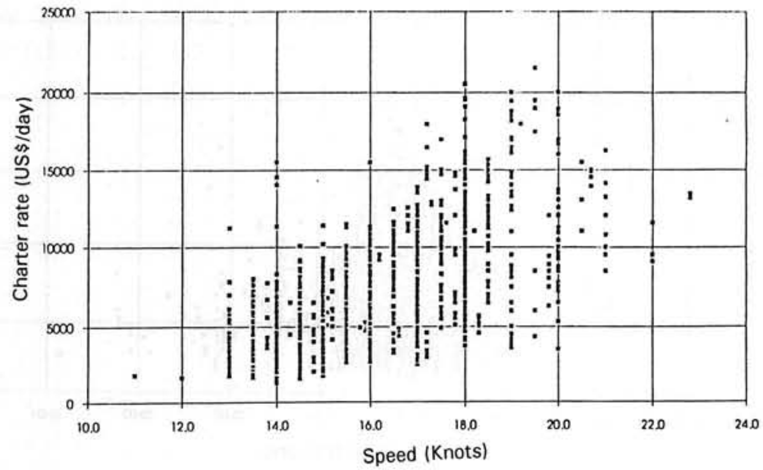


Figure 19: Charter rates in US$ per day as a function of service speed

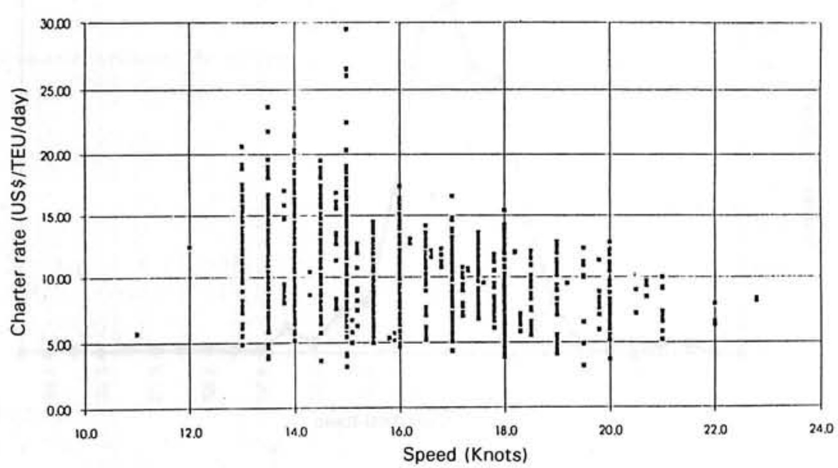


Figure 20: Charter rate in US$ per TEU per day as a function of service speed

The main factors for the voyage costs are fuel consumption, port and canal fees, and cargo handling costs. The charterers intend to minimise the sum of charter costs and voyage costs. A ship with a high fuel consumption and therefore a high voyage cost level, will have a lower charter rate. **Figure 21**, **Figure 22** and **Figure 23** show relations between the fuel consumption, the charter rate, the ship size and the speed.

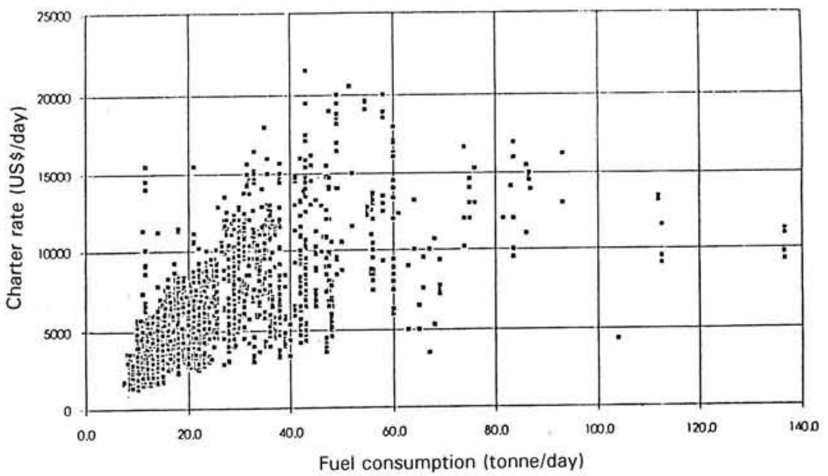


Figure 21: Charter rate in US$ per day as a function of fuel consumption

8.5.2 Charter market index

When all charter rates are plotted against time, see **Figure 24**, a general price trend can be observed. The most important objective of a charter index is to reflect rate fluctuations due to general market behaviour. Rates are the result of a difference between supply and demand on the charter market.

The index is a thermometer indicating the market situation. It tries to combine all technical aspects in order to eliminate them, leaving only an index value about the market at a certain time. In the next sections this index is used to find relations between the design characteristics and charter rate. The purpose is to eliminate the variance, caused by the economic business cycle to get the charter rate per ship at comparable levels over a long period of time.

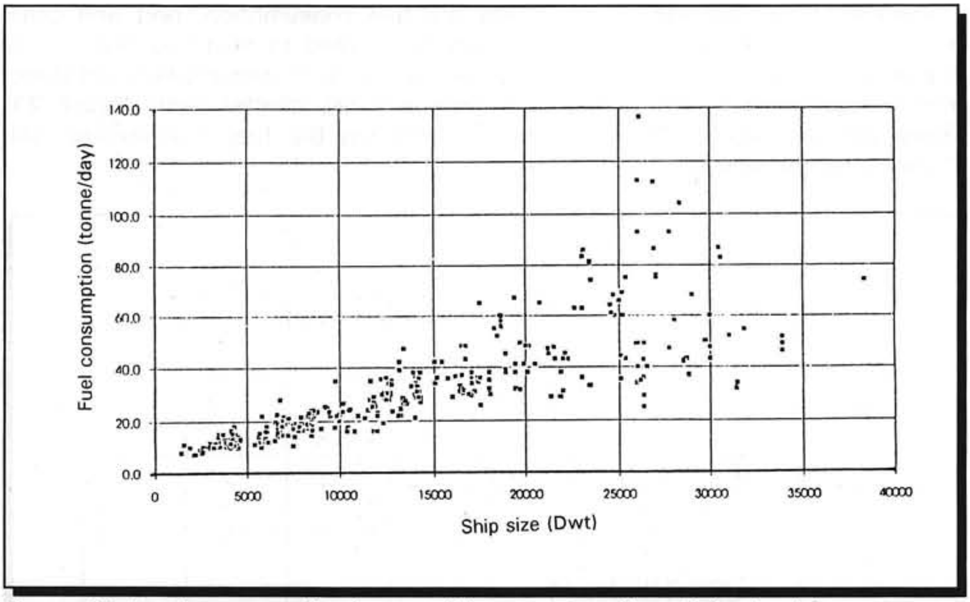


Figure 22: Fuel consumption in tonne/day as a function of deadweight

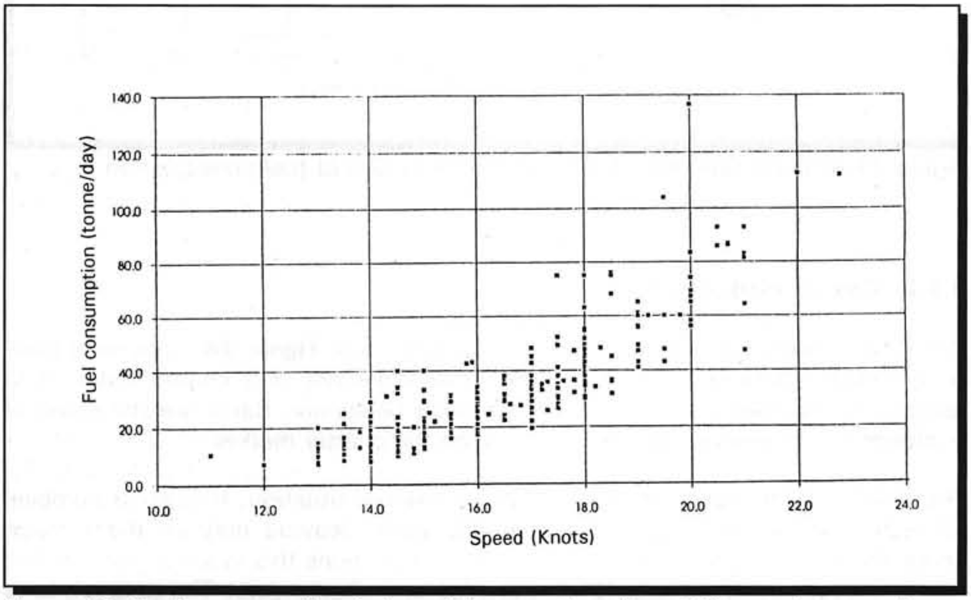


Figure 23: Fuel consumption in tonne/day as a function of the service speed

The index incorporates the price fluctuations of the ships of different size categories per period. It would be best if there would only be one index for all

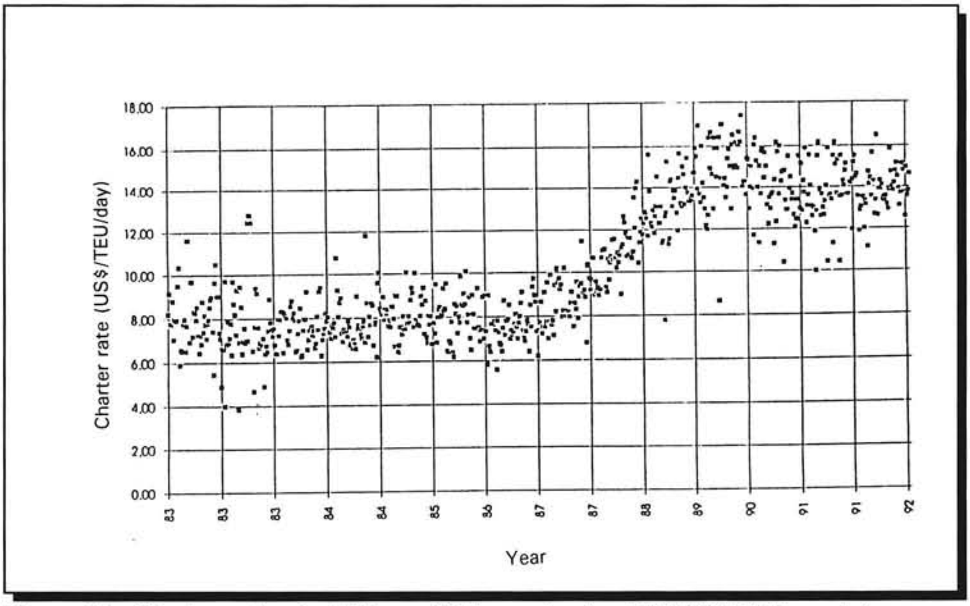


Figure 24: Charter rates in US$ per TEU per day for 400-600 TEU container ships

ships. This would reduces complexity and also simplifies the calculations. However, because there are big differences between the different ship sizes, it is not possible to combine ships of all different sizes in one index. Therefore, a subdivision was made. The segmentation was carried out on basis of the number of fixtures per ship size category. The fixtures are more or less divided equally over each category. On that basis the following subdivision was made (only cellular ships that are still trading):

- 100-400 TEU;
- 400-600 TEU;
- 600-1000 TEU;
- 1000-2000 TEU.

Also important for the index is the choice of the point that is chosen as 100. It should not be a in period in which there is an excessive number of fixtures. Besides, it is preferable that this initial value is not too long ago. These are the reasons why January 1992 is chosen. Then the rates were at a fairly constant level.
The intermediate period for the index is a quarter of a year. A period of a year is too long, because within a year a lot can change. A period of a month too short, because then there are not enough fixtures per period.

Interesting are the weighted charter rates, which are shown in **Figure 25**. Here the charter rates are related to the capacity of the ship. Per time interval of a quarter of a year all charter rates are added and thereafter divided by the sum of all chartered TEUs:

$$\frac{\Sigma\ Charter\ rate_i\ (US\$/day)}{\Sigma\ Capacity_i\ (TEU)}$$

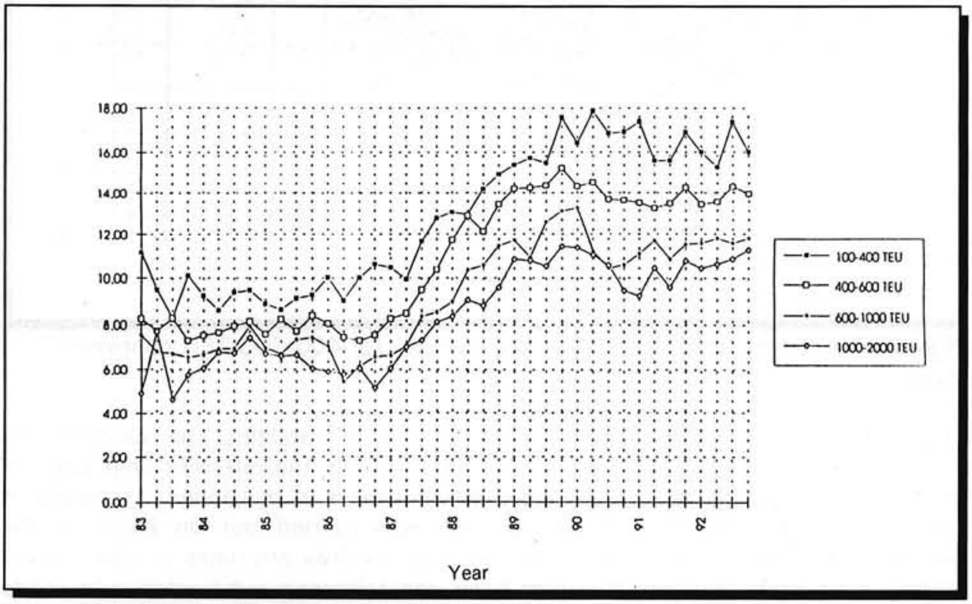


Figure 25: Weighted average charter rate by quarter

The objective of this study is to compare the charter rates of the container ships over a long period of time in order to identify above and below average performance. To eliminate the effect of the world business cycles, the charter rates in each period are divided by the time charter index for that period. The basic assumption is that the relative performance of the ships is thus obtained, while the unpredictable 'noise' of the world economy is neutralised. Now a rate level can be set and the fixtures and the fixed ships with the highest deviations can be detected. These deviations are found in the following scatter diagrams, showing the charter rate of each fixture divided by the index.

In the scatter diagram, three groups can be distinguished. A group above average, a group below average, and a group of ships that have an indexed charter rate of about average. For each ship size category a minimum and a maximum charter rate per TEU was determined, to define under- and outperformance.

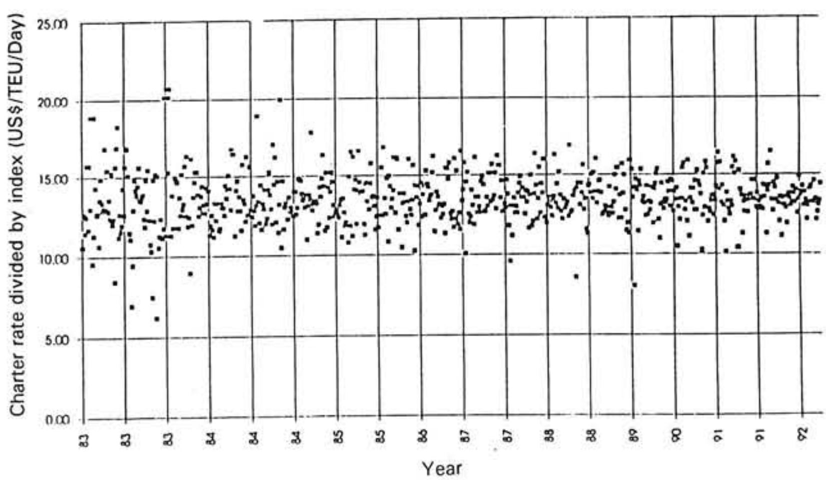


Figure 26: Charter rate divided by time charter index

▸ 100-400 TEU	< US$ 14	or	> US$ 20
▸ 400-600 TEU	< US$ 12	or	> US$ 15
▸ 600-1000 TEU	< US$ 10	or	> US$ 13
▸ 1000-2000 TEU	< US$ 9	or	> US$ 12

There are three possible major causes of under or outperformance:

- *The quality of the vessel*
  Not only the technical performance is important in this matter, the quality of the vessel also depends on the management, the crew, the flag and the reliability (i.e. the off hire period);
- *The contract*
  The variation in contract depends on the period, early positioning, type of contract and area;
- *Market mechanism*
  The general market cycles have been eliminated by the index, but in specific regions, for example the Caribbean or Australia, especially those regions with few competitors, there can be an imbalance between actual demand and supply.

8.5.3 Ratios

This sections shows ratios of design characteristics. The ratios have been calculated for the selected under- and outperforming ships. The following ratios are shown in the graphs:

- L/B;
- B/T;
- L/D;
- D/T;
- B/D;
- Dwt/(L*B*T);
- Froude number;
- GT/TEU;
- Dwt/TEU;
- Age.

Every figure shows on the horizontal axis the ship size and on the vertical axis an index figure that represents the value of the ratio of each ship compared to the average (= 100);

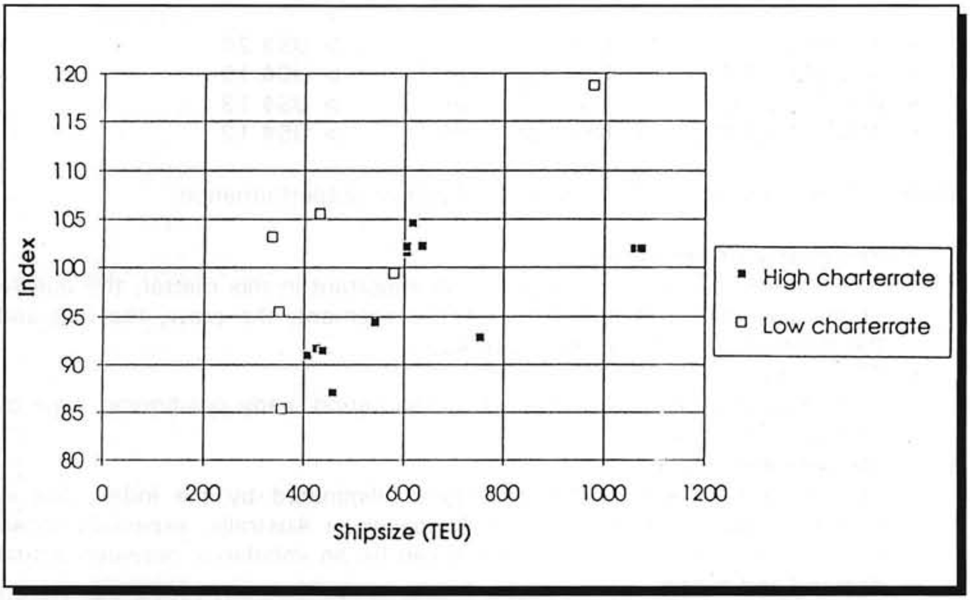


Figure 27: L/B-ratio

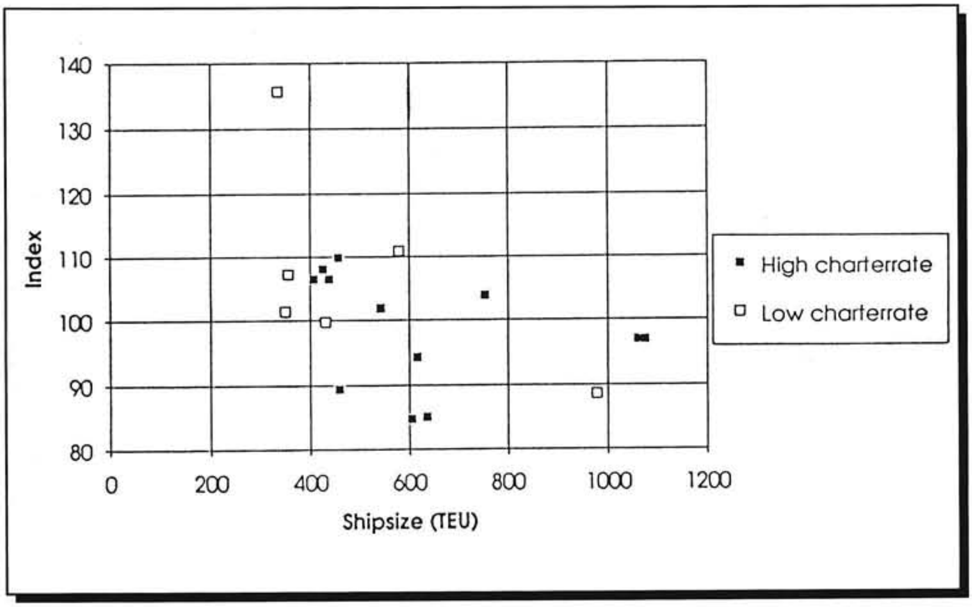


Figure 28: B/T-ratio

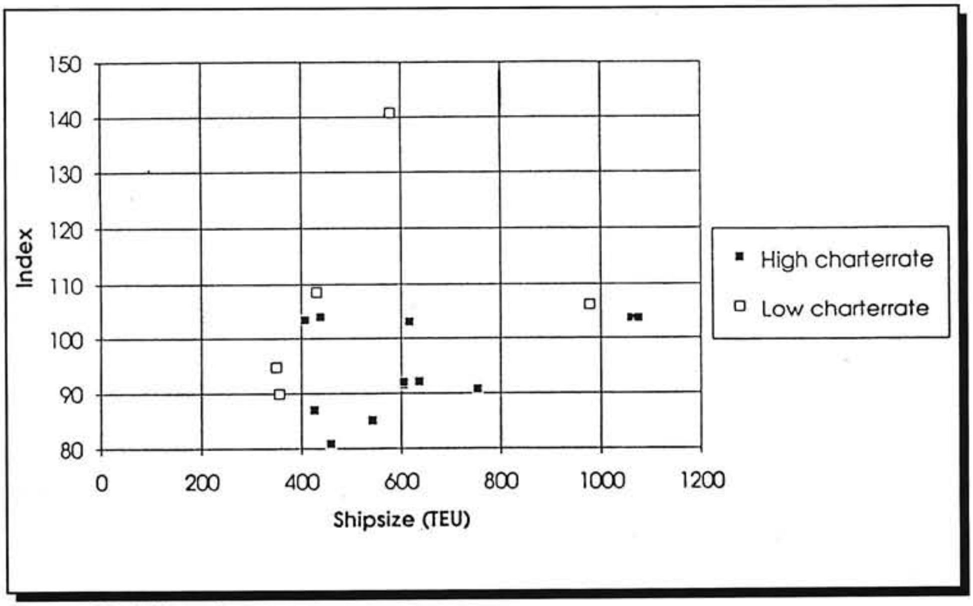


Figure 29: L/D-ratio

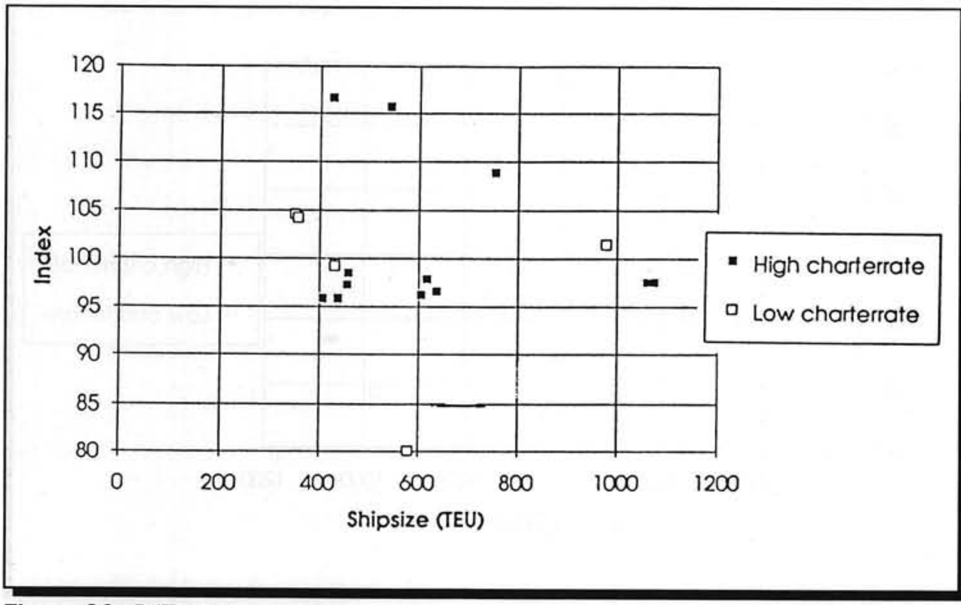


Figure 30: D/T-ratio

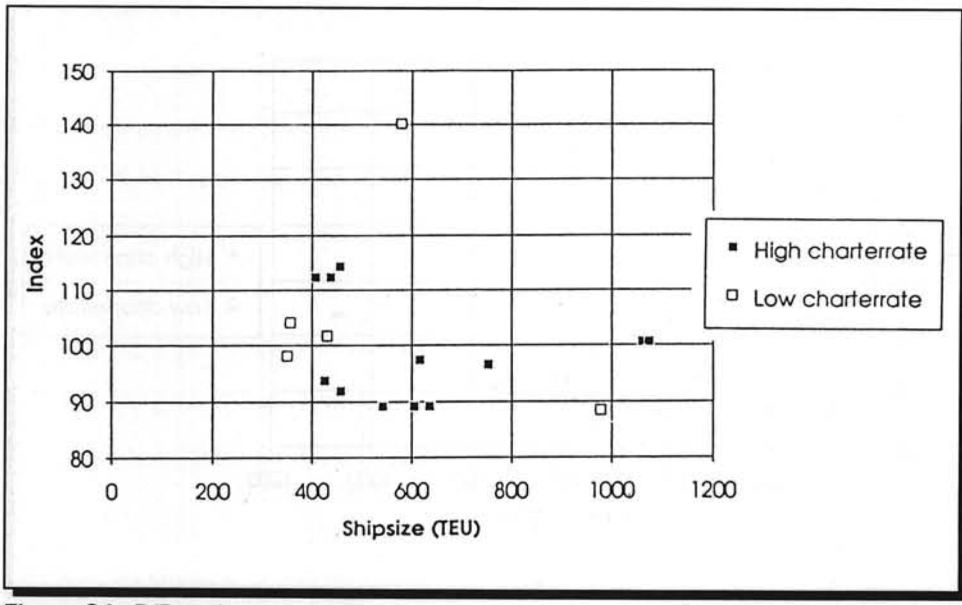


Figure 31: B/D-ratio

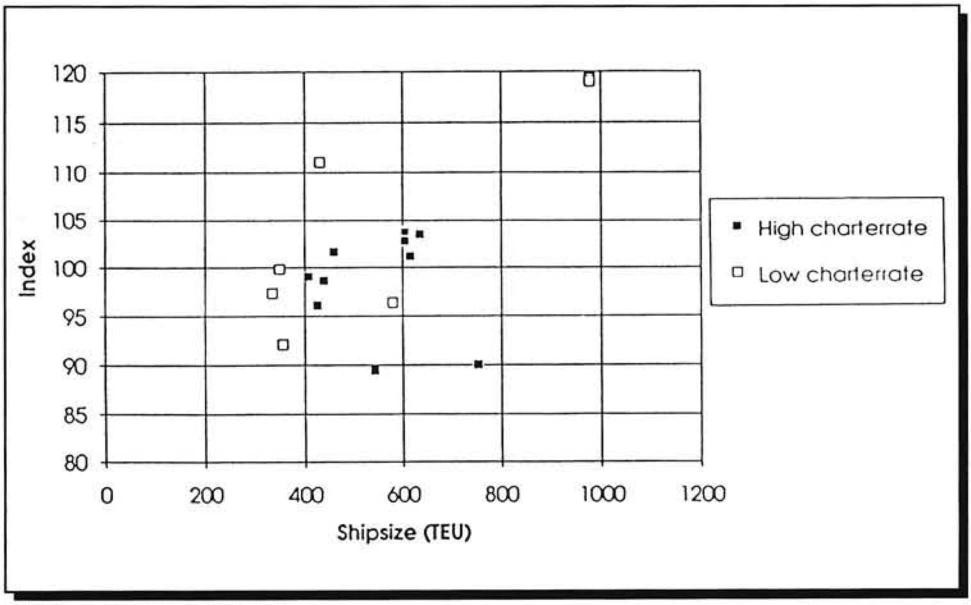


Figure 32: Dwt/(L*B*T)

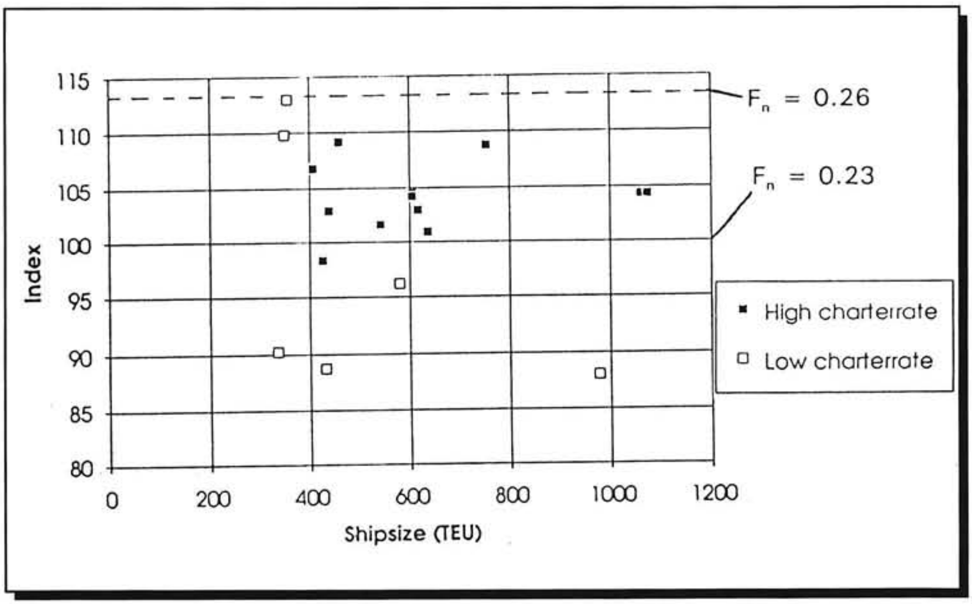


Figure 33: Froude number

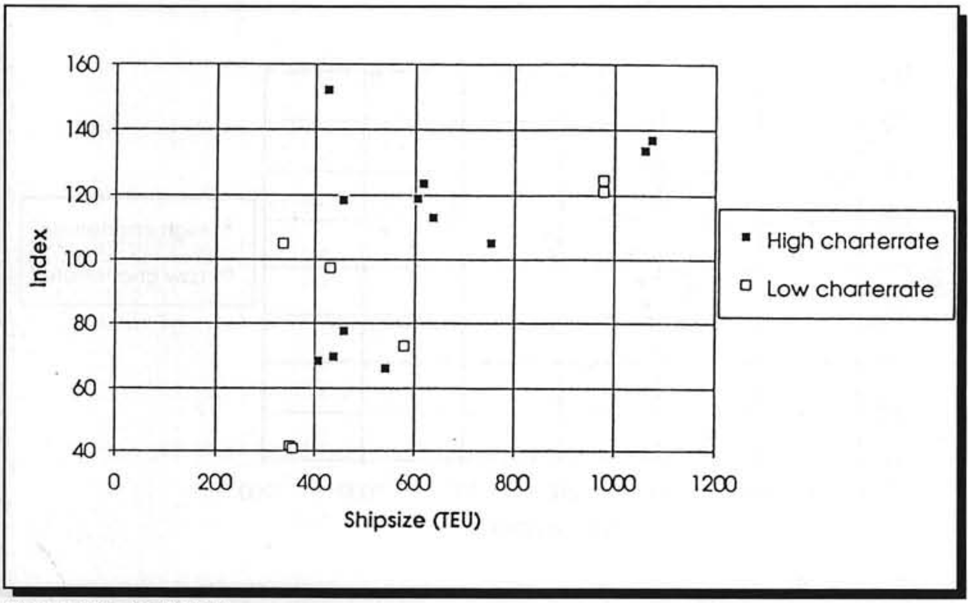


Figure 34: GT/TEU

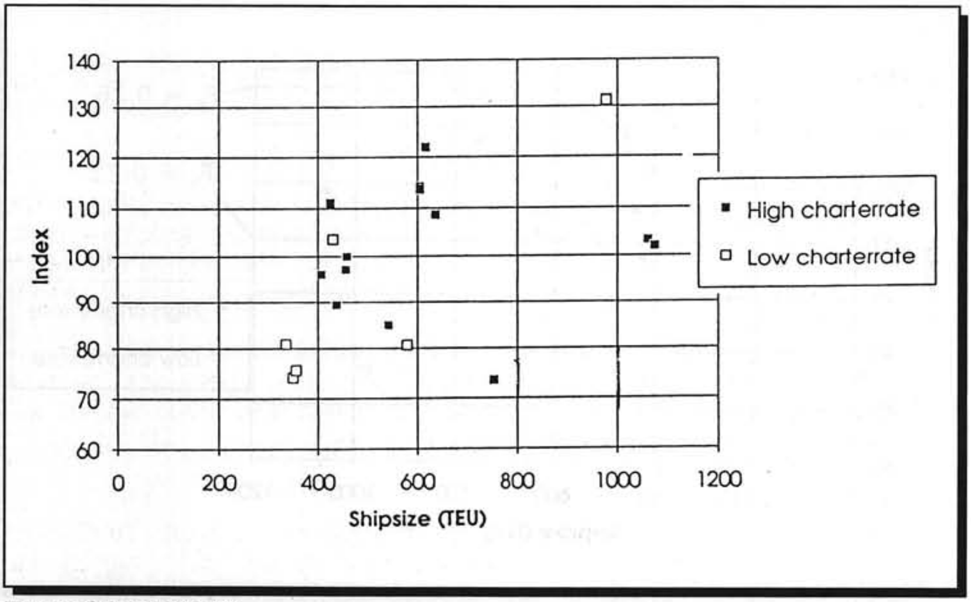


Figure 35: Dwt/TEU

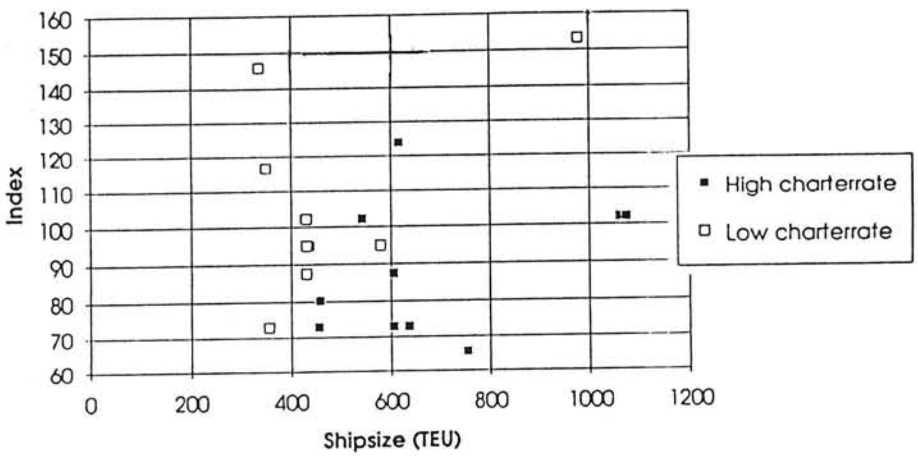


Figure 36: Age

8.5.4 Analysis of the charter rates

For the analysis, the ships are divided into three categories, on basis of their use:

- *Shortsea feeders (smaller than 400 TEU);*
  Deadweight is important for this category of container ships. The deadweight/TEU ratio should be higher than the average, which means at least 17 tonne/TEU. This is because of the fact that the distribution of heavy and light containers is more difficult to handle on smaller vessels than on larger ones.
  A low GT is very important for small vessels, which often call ports almost on a daily basis. Generally, these vessels do not have gear, because the ports are always well developed. A bow thruster has several advantages because of the frequency of port calls.

- *Common feeders (400-900 TEU);*
  This category comprises a relatively wide range of ship sizes. To obtain a high flexibility these ships are often self-sustained and have a high speed. Vessels with a high charter rate often have a Froude number higher than the optimal of 0.26. The speed is more than 15 knots for ships smaller than 600 TEU and at least 16 knots for larger ships. Vessels with a low speed are chartered at low charter rates.

These vessels are often chartered on short term periods or for round-voyage time charters. This causes a greater risk for the owner and the charter rates may vary strongly. To obtain lower running costs a low GT can restrict the crew number and decrease the manning costs. Compact types are performing well, especially in this size range. Deadweight is of minor importance, but it is usual for this group to have a dwt/TEU-ratio of about 16 tonne/TEU. Again, it is advantageous for these ships to have a bow thruster.

- *Dedicated feeders (larger than 900 TEU);*
  Generally, these feeders were designed for a specific trade and do not have the flexibility of the common feeders. The performance of such a vessel in the charter market depends on its flexibility. Therefore, the design should be based on the possibility that the ship, after service for a specific operator, will be operated in the charter market. Speed should exceed 18 knots, for vessels of 1000 TEU. The number of containers in the hold in relation to the total capacity does not have to be very high. The GT is for larger vessels of minor importance, while these ships do not enter ports very often and their safe manning requirements change very little with a change of the GT.

The most important design characteristics in relation to the charter rates are:

- Capacity;
- Deadweight;
- Speed;
- Fuel consumption;
- Gross tonnage and nett tonnage;
- Cranes;
- Bow thruster;
- Type of hatch cover.

All decisions in relation to these design characteristics depend generally on the feeder type. For the ships in the charter market, mainly shortsea and common feeders, for each specific item a high flexibility has to be taken into account against higher building and higher operating costs.

The *capacity* of the ships should be as high as possible, as the charter hire strongly depends on capacity. The charter rate decreases when the capacity increases. Generally, there is demand for a certain TEU size, from an operator who wants to operate the ship in a situation where there is a specific cargo flow. Capacity is a major design demand so in general there is not much flexibility on this subject for the designer.

The *deadweight* is strongly related to the TEU capacity. The deadweight/TEU ratio is approximately the same for each size, about 17 tonne/TEU.

While deadweight includes cargo as well as stores and bunkers, the average sailing range of the ships is not that high that problems may occur. When there is a severe deviation from the average this negatively influences the charter hire.

To obtain a high flexibility of the vessel, which is necessary in the charter market on a long term basis, the *speed* must exceed a certain minimum. The Froude number must be at least 0.23. The higher investment for a larger engine generally pays.

The *fuel consumption* is especially important for the larger vessels, because the consumption is part of the economies of scale. The development of voyage costs against ship size in TEU is equal to the development of capital costs per TEU as a result of the economy of scale. When the fuel consumption of one vessel is 10 tonne/day higher than a ship that is equal on all other aspect, voyage costs will increase with US$800 per day at a fuel price of US$80 per tonne. Also important is the reliability of the engine, and charterers do take the type of engine into account when they charter a vessel.

The *gross tonnage* and *nett tonnage* should be as low as possible for the charterer, who wants to pay low port and canal fees. Owners want to have a low GT because of the manning requirements. Many owners have anticipated on this issue. Ships have been subject to every trick that can be applied to obtain a minimum measurement. A minimum freeboard, minimum accommodation space, holes in the crane foundation structures and a maximum deck cargo are a few to mention. The container ship charter market is dominated by ships with a small depth. Disadvantages are construction problems for obtaining the necessary longitudinal strength and a low dynamic stability. Ships with exceptionally low tonnage measurements have low charter rates.

Cranes seem to be very essential, not only for common feeders. They can be necessary to maintain flexibility on places where the vessels cannot be unloaded by the terminal. The investment in cranes is quite high, but a trade off can be calculated against a general charter rate increase of US$1/TEU/day. For a 600 TEU container ship this could result in an increase in income of approximately US$200,000 per year.

Generally, a *bow thruster* is very useful for vessels smaller than 900 TEU. Then often tug assistance can be avoided. The costs of tug assistance are relatively high, especially when the ship enters many ports.
Ships that enter many terminals are more economical when they are fitted with foldable *hatch covers*. These can be operated by the crew of the vessel, independent from terminal gantry assistance. Often pontoon type hatch covers are fitted to the larger vessels. This type of hatch cover can only be lifted when all containers on top of it are removed. The cargo in the hold can be reached more easily but each lift is brought into account by the terminal at an equal price as a move. Hatchless container ships of course have great advantages.

CHAPTER 9: DIFFUSION OF INNOVATION

An invention usually leads twenty years later to a basic innovation, which takes another period to be diffused and replace an existing technology, product or service. Rogers has studied the way in which innovations spread around the world and displace existing products (in *"Diffusion of Innovation"*). He has developed a conceptual model of the diffusion process, which is shown in **Figure 1**.

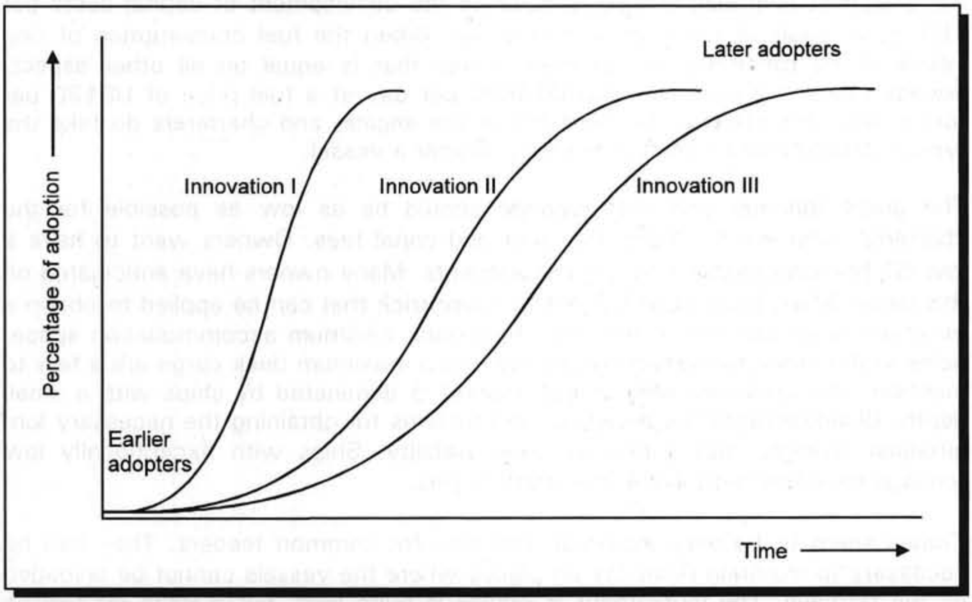


Figure 1: Conceptual model of the diffusion process of innovation

In order to understand the mechanics behind the rate of adoption of innovation another model of Rogers can be used (**Figure 2**). He identifies five key-variables:

1. *Perceived attributes of innovations*; relative advantage over alternatives, compatibility with values, past experiences and needs, complexity, tri-ability and observability;
2. *Type of innovation*; innovations requiring an individual optional innovation decision will be adopted more rapidly than when an innovation has to be adopted by an organisation;
3. *Communication channels;* if interpersonal channels must be used, the rate of adoption will be slowed down provided the innovation is not perceived as complex. In the case, interpersonal channels are more effective;

4. *Nature of social system*; in particular the degree of interconnectedness, i.e. how effectively the members of a social system are lined by communication networks, is positively related to the rate of adoption;
5. *Extent of a change agents' promotion effort*; which is most effective at the early stages of the diffusion process, when opinions are forming.

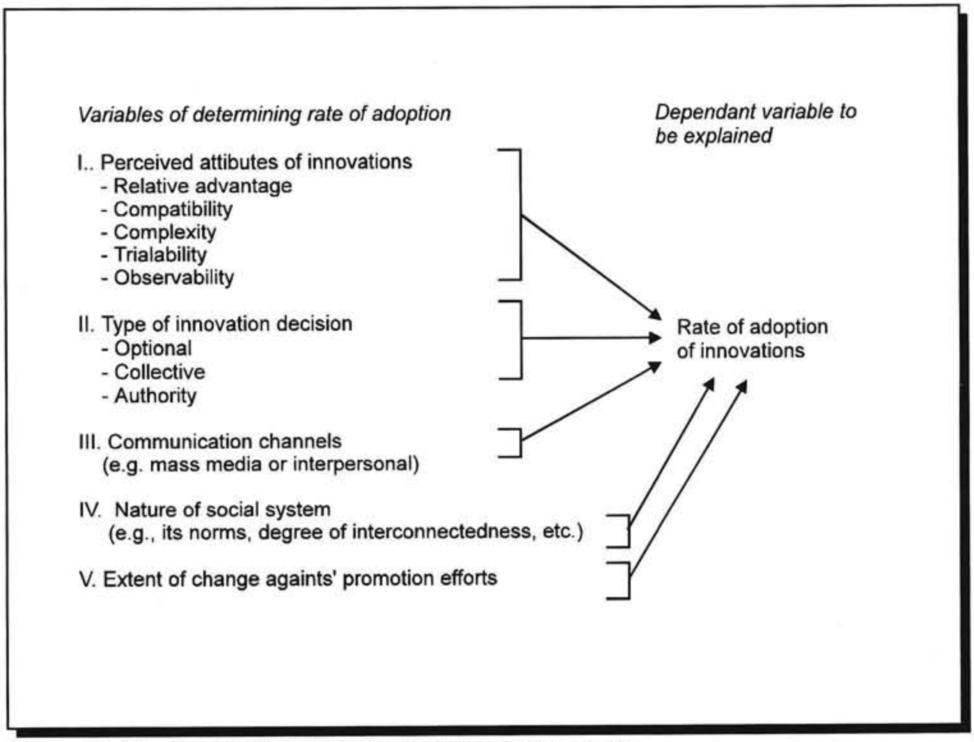


Figure 2: The key-variables for adoption of innovation

The diffusion process seems hard to define in reality. However, prof. C. Marchetti of the International Institute for Applied Systems Analysis IIASA, has developed a scientific basis for the measurement of the diffusion process. The following is based on a number of his papers.
After studying innumerable cases of innovation diffusion, he came to the conclusion that the searching, invention, developing, enterprising, selling, all follow the same pattern or mechanism, which can be characterised by the same mathematical function: the mathematics of epidemic diffusion at the various hierarchical levels.

9.1 Diffusion process: the logistic

A real epidemic can be mathematically defined by the number of individuals $\overline{N}$ in a population that is infectable and the number of individuals N that already have been infected. The new entries in the infected area can be represented by the equation:

$$dN = aN(\overline{N} - N)dt \tag{10}$$

This expression means that these new entries (victims) in time, *dt*, are proportional (*a*) to the product of the infected individual (*N*) spreading the epidemic and the suspectible individuals still around ($\overline{N} - N$). The solution of the equation is:

$$N(t) = \frac{\overline{N}}{1 - \exp[-(at + b)]} \tag{11}$$

where:

b = integration constant.

Calling $F = \overline{N}/N$ we can rewrite equation (2) in the form:

$$\log(F/1 - F) = at + b \tag{12}$$

which is a straight line known as the Fisher-Pry transform.

Equations (11), (12) and (13) are reported in **Figure 3**, **Figure 4** and **Figure 5**. **Figure 4** is the S-curve, called the *logistic*. In **Figure 5** the S-curve is straightened by the Fisher-pry transform, t_0 is the time of the maximum rate of diffusion.

To give the rate (*a*) of the process in an intuitive form, it is expressed in terms of the time *T*, the plague takes to go from 10% of *N* to 90% of *N*. These two points are marked in the figures by crosses. The relation between *T* and ***a*** is the following:

$$\Delta T = 4.39a^{-1} \tag{13}$$

In the graphs that follow, the value $\overline{N}$ is usually reported as a number in parenthesis, and t_0 is given as a date.

Figure 6 shows the diffusion of the London plague from 1665, which caused the death of 54,700 persons. It confirms the hypothesis that the death rate is a constant proportion of infections, and that the epidemic follows the logistic or S-curve.

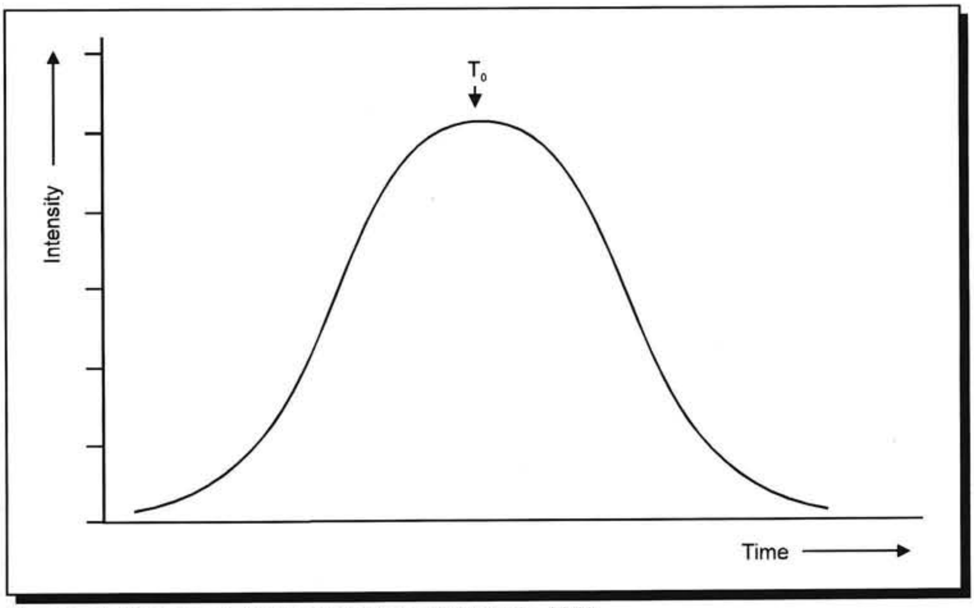


Figure 3: Graphical representation of formula (11)

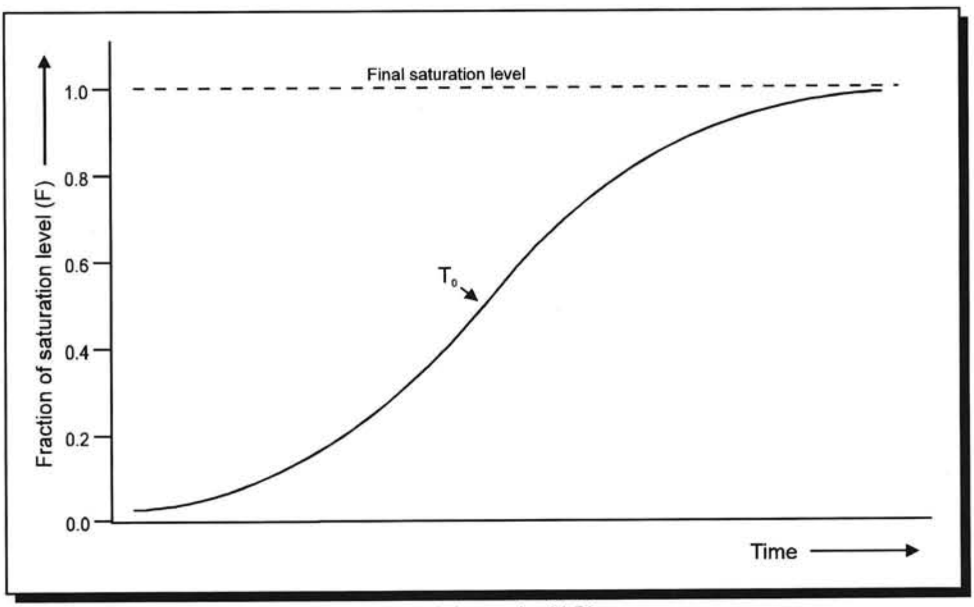


Figure 4: Graphical representation of formula (12)

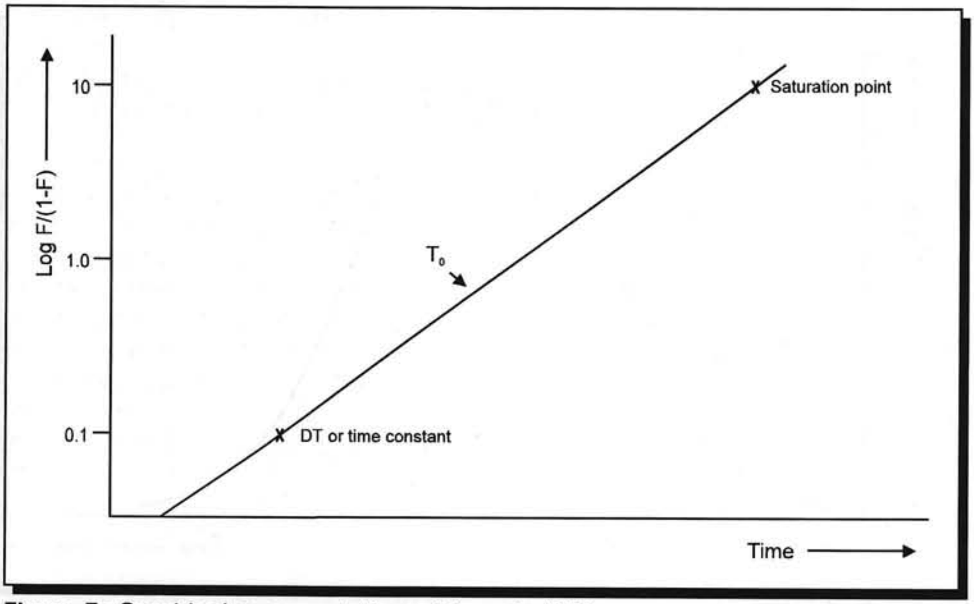


Figure 5: Graphical representation of formula (13)

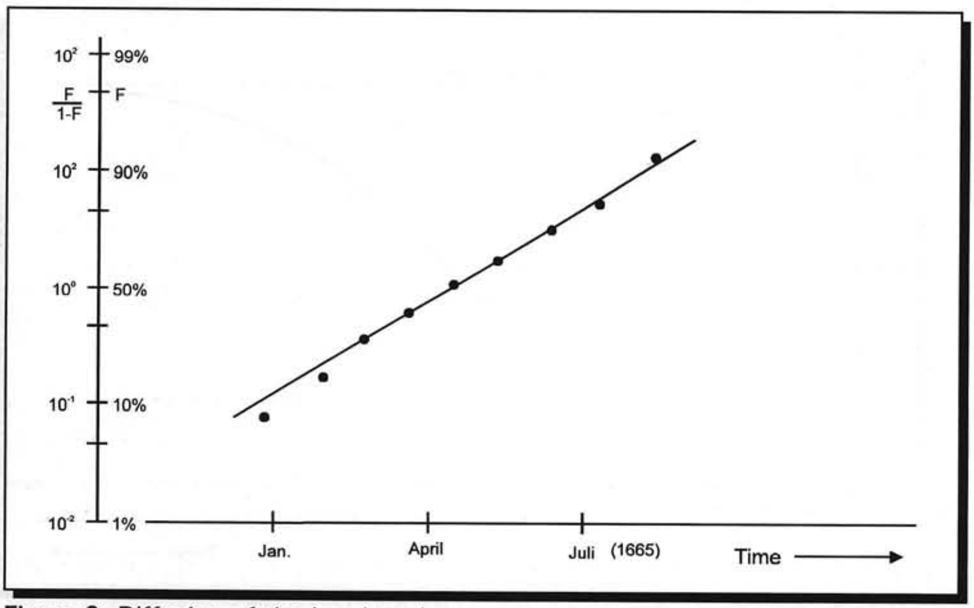


Figure 6: Diffusion of the London plague

John Casti in *"Complexification; Explaining a Paradoxical World Through the Science of Surprise"*, uses one illustration that is based on the work of C. Marchetti. This shows the growth of a bacterial colony over time, which seems to follow the same simple pattern, which biologists call the *logistic*, or S-shaped curve.

Figure 7 shows the development of a bacterial colony; the right half of the figure shows the same S-shaped curve plotted in coordinates using the quantity F/(1-F), where F represents the fraction of the final system size. So, for example, the ratio F/(1-F) equals 1, the system has reached 50 percent of its final size, and when this quantity equals 100, the system is at essentially 100 percent of its final size. This kind of plot is convenient, since any process whose behaviour obeys the S-shaped logistic rule appears as a straight line when plotted using the ratio F/(1-F). The logistic growth of bacteria is very simple, based on the available amount of nutrient. Nevertheless, these patterns appear in areas where there is no obvious quantity available to play the role of nutrient or scarce resource.

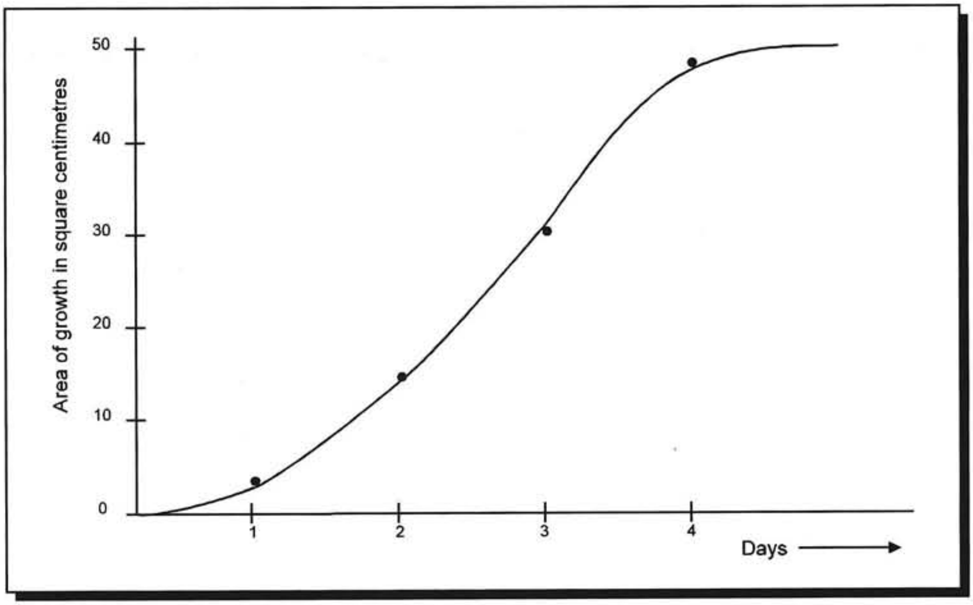


Figure 7: The development of a bacterial colony

The question is whether the S-curve diffusion process can also be demonstrated on products instead of deaths and bacterial colonies. **Figure 8** shows the construction of Gothic cathedrals in Europe. The construction of 220 cathedrals peaked in 1250, and the development perfectly fits the S-curve.

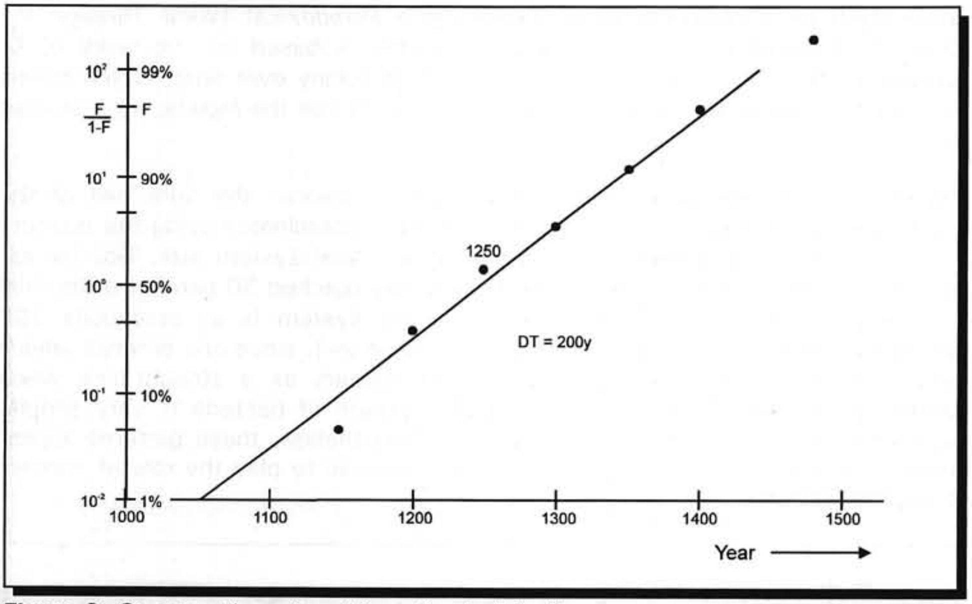


Figure 8: Construction of gothic cathedrals in Europe

Figure 9 shows the diffusion of cars in Europe during a hundred year period. There are two curves, one before the Second World War, and one thereafter. The first curve had its maximum rate of diffusion in 1930 and the total number of prewar cars was 7.5 million; the second postwar curve had its maximum rate of diffusion in 1970, 40 years later, while the total car population increased to 150 million.

Figure 10 shows the growth of the number of mainframe computer makers that entered the market at least with one model. Their cumulative number grows logistically and saturate to 700; the maximum entrepreneurial activity is situated around 1991.

9.2 Correlation inventions and innovations

Marchetti's research also demonstrates that invention and innovation activity seen in a historical perspective are quite ordered and well-regulated operations. Both come in waves, as Kondriatiev already postulated, and each wave can be organised as if it were a diffusion wave of a quite abstract nature, which Marchetti calls the *action paradigm*.
Based on the data collected by G. Mensch and summarised in **Chapter 4,** Marchetti has applied the logistic to the different invention waves. **Figure 11** shows the 1802 wave, in which the invention peaked in 1775, while the in-

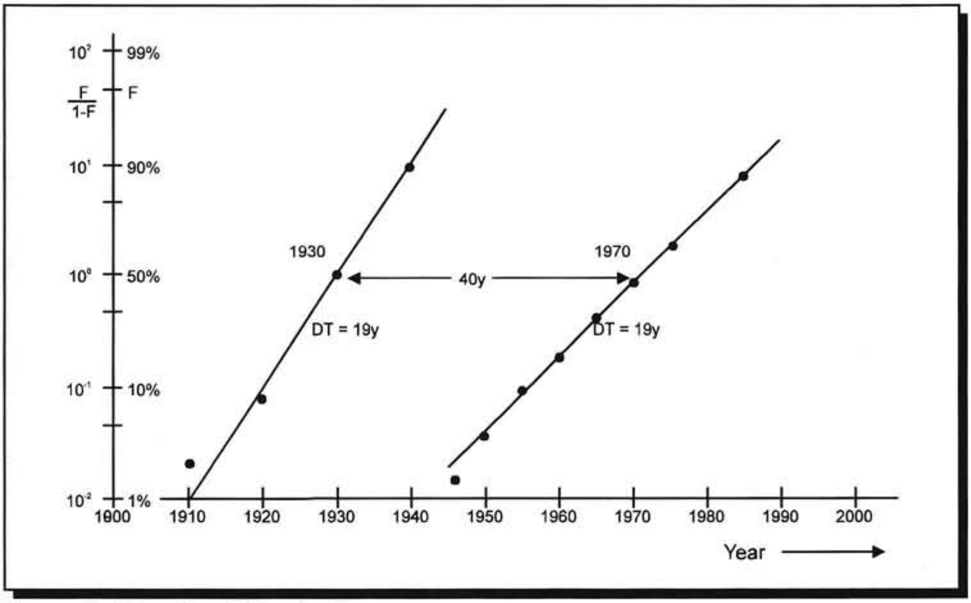


Figure 9: Car circulation in Europe

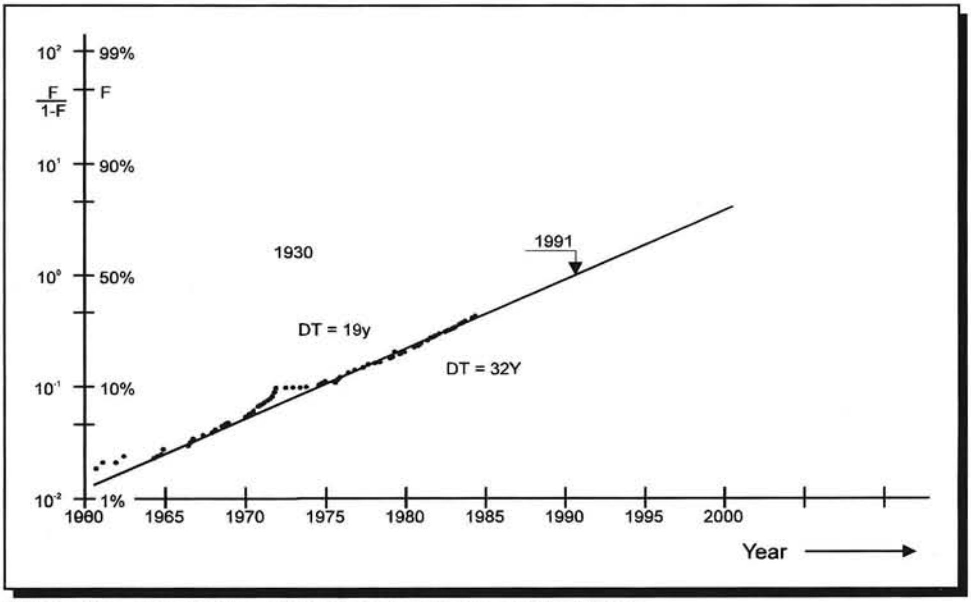


Figure 10: Population of new computer manufacturers

novation wave peaked in 1828. The two waves are 55 years apart, which was already discovered by Kondratiev.

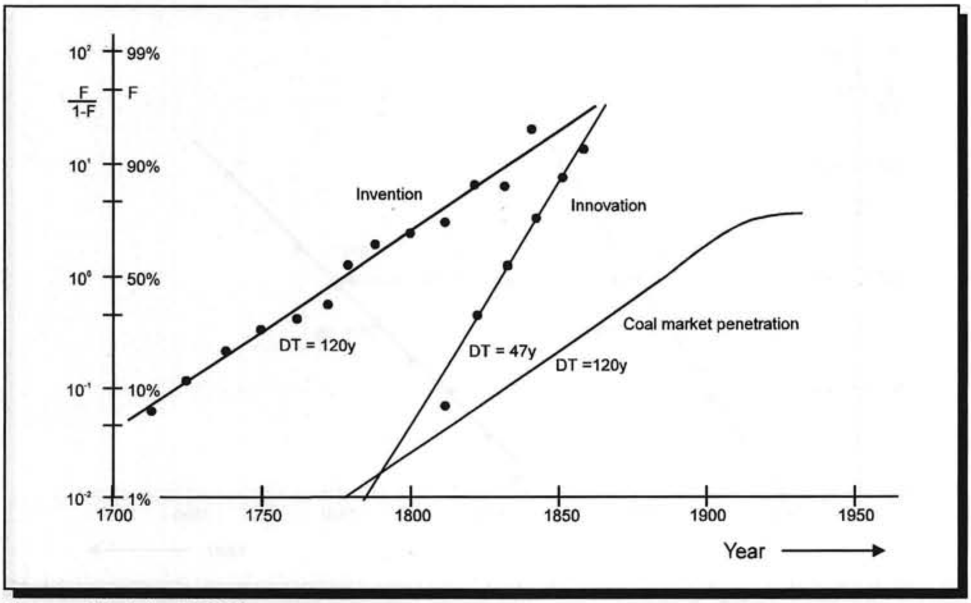


Figure 11: The 1802 wave

Mensch identified two more waves of invention-innovation called the 1857 Wave and the 1920 Wave. These are shown in **Figure 12** and **Figure 13**. Based on the same principles, Marchetti added a fourth wave, which is situated in our times, and shown in **Figure 14**. The four waves are shown in **Figure 15**, which confirms the Kondratiev assessment that most innovative activity occurs near the throughs of the cycle.

This is further illustrated by **Figure 16** in which variations in energy consumption in the U.S.A. - which are closely related to the general level of economic activity - are plotted over a 160 year period. This graph also shows the positioning of the centre points of the previous three waves of invention-innovation. Innovations appear locked to the waves, but inventions keep shifting their phase, advancing toward innovations.

Figure 17 shows yet another illustration of the logistic, based on a historical overview of the development of large transport infrastructure systems in the U.S.A.: canals, railways, and paved roads. They are measured as percentage of their final length, and presented in linear coordinates (no Fisher-Pry transform). Their centre points are 55 years apart, and are locked six years after the troughs. Marchetti comments that ***"the activity in infrastructure construction is the Keynesian patchwork recipe to alleviate recession is well-known, but all that precision in the long-term construction activity was at all unexpected"***.

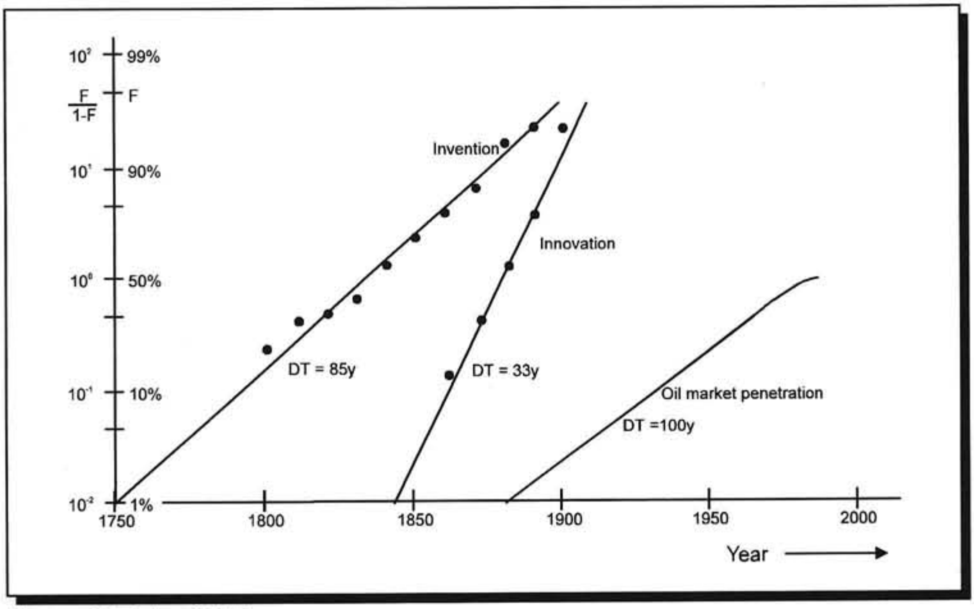


Figure 12: The 1857 wave

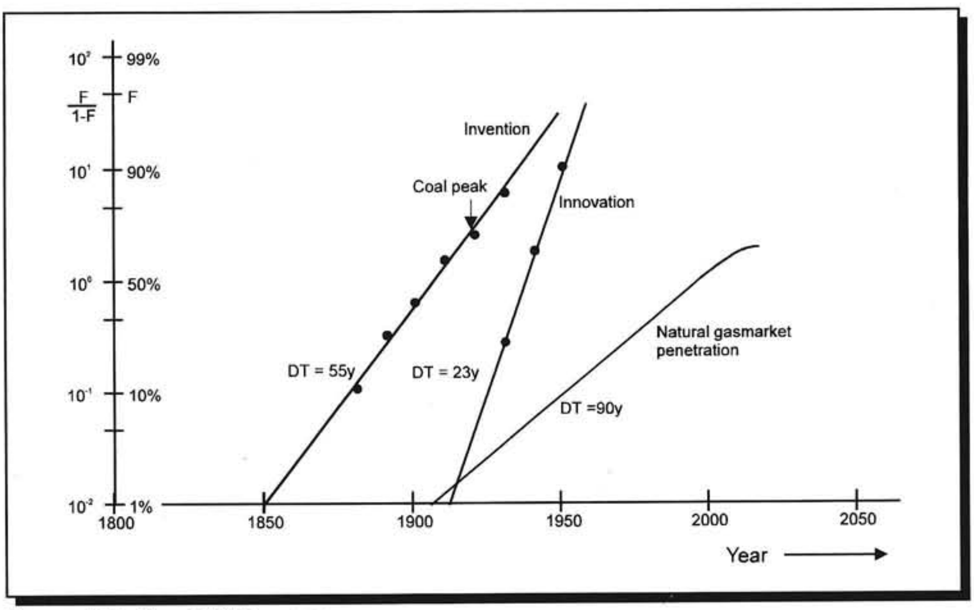


Figure 13: The 1920 wave

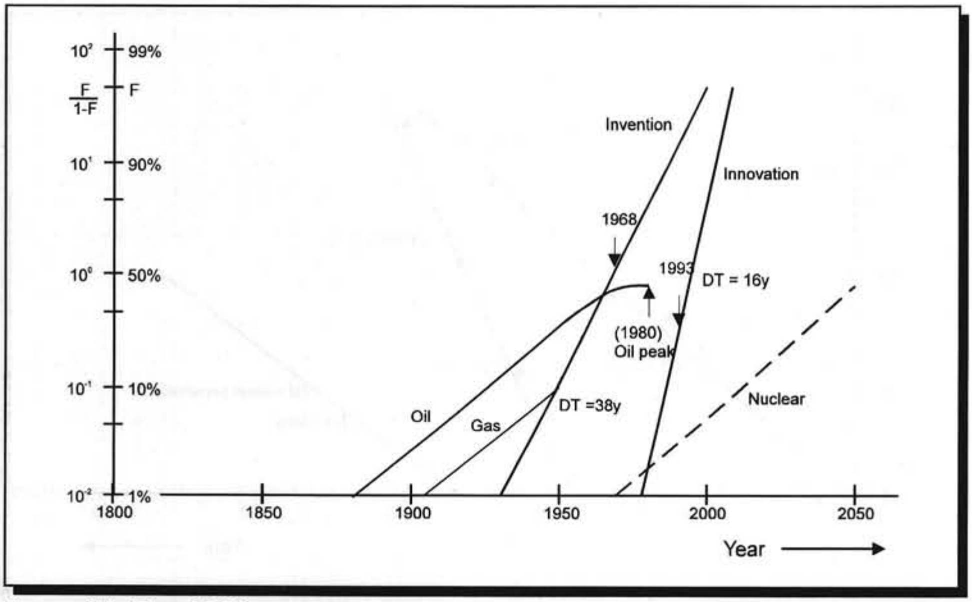


Figure 14: The 1980 wave

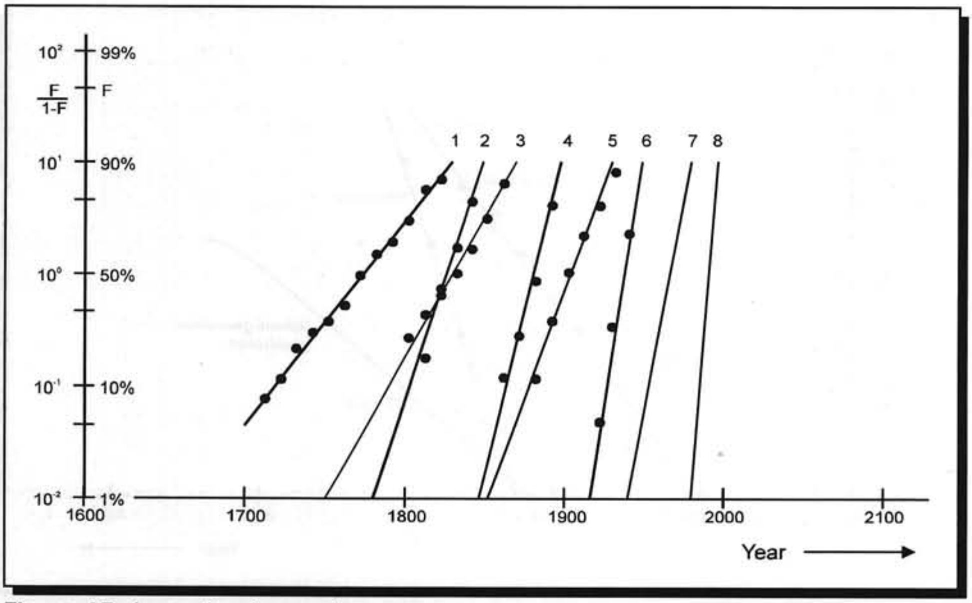


Figure 15: Invention-innovation waves

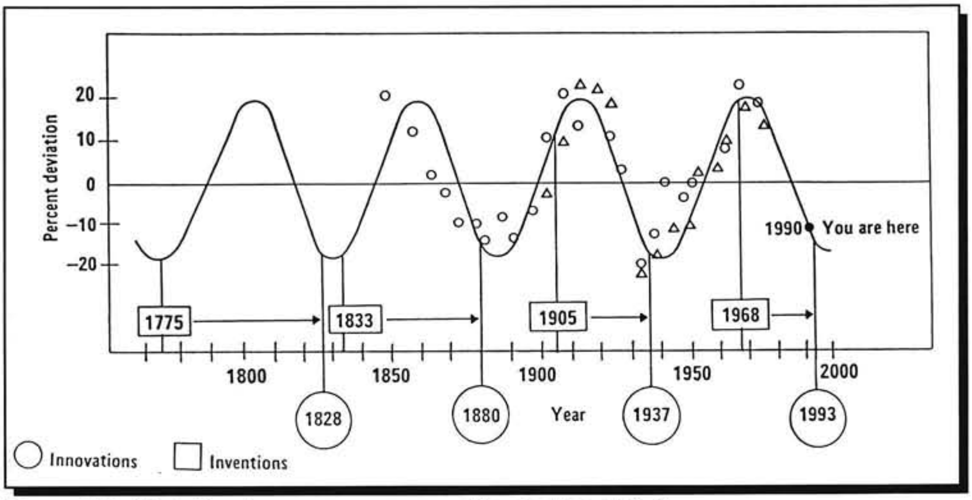


Figure 16: Variation in energy consumption in the U.S.A.

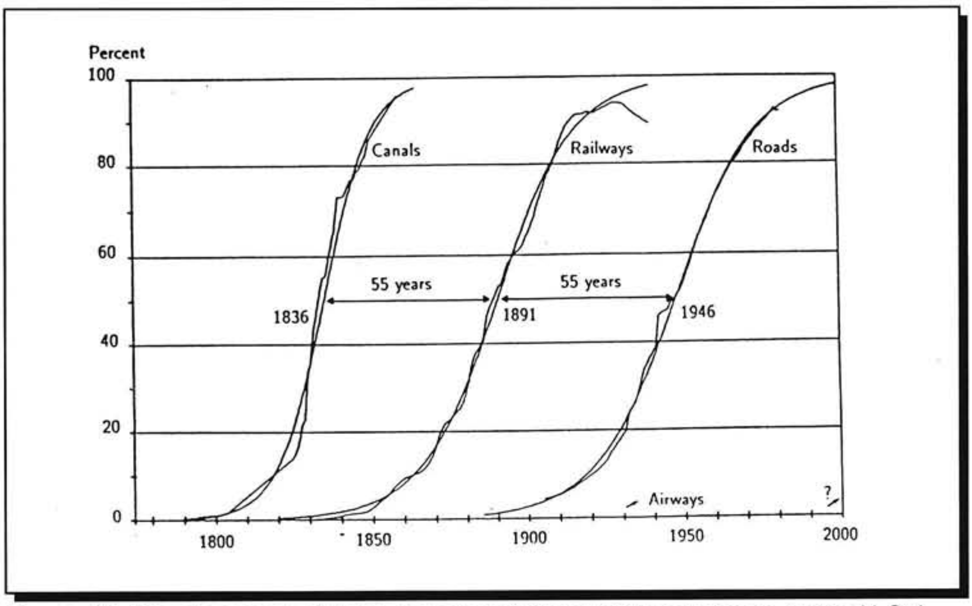


Figure 17: Development of large transport infrastructure systems in the U.S.A.

The future is now

How can one identify how much has still to be discovered in a certain area. Because discovery is so precisely organised, the evolution of the rate of discovery in the past permits to calculate the dimensions of what remains to be discovered. Marchetti demonstrates the strength of his logistic concepts on the basis of the discovery of the chemical elements over the last two centuries. They are the elements not already known in current practice since antiquity, like iron, copper, silver, gold or sulphur. The results are shown in **Figure 18**.

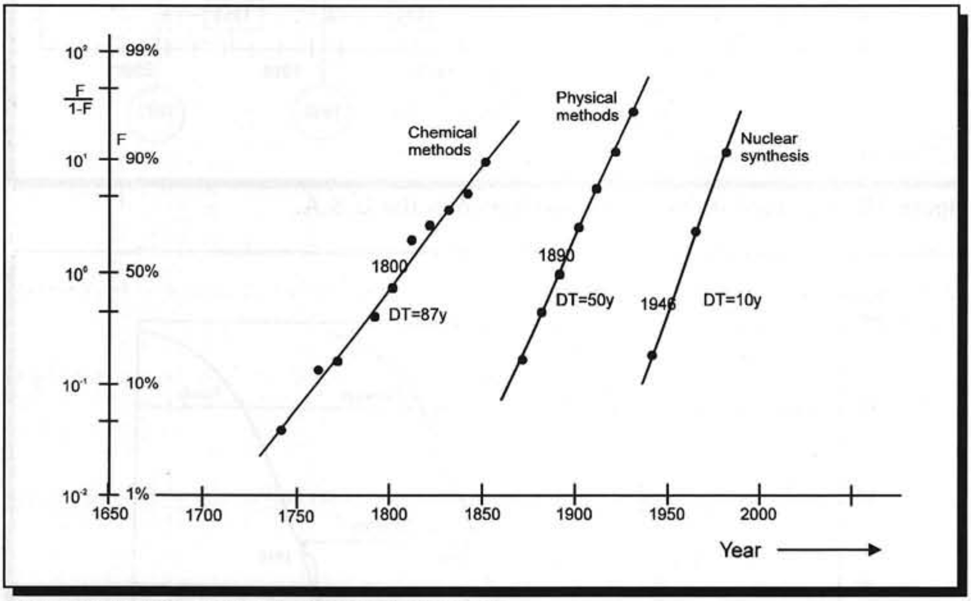


Figure 18: Discovery of chemical elements

S-curve and technological performance

In **Chapter 7**, the relation is demonstrated between the effort (investment) to develop a technology (product, service) and the resulting increase in performance. Marchetti provides at a high conceptual level yet another example of tracking performance, based on the indicator ε = thermodynamic efficiency. This efficiency is plotted as ratio of $\varepsilon/1-\varepsilon$, efficiency over inefficiency, and the data are fitted with a logistic equation and shown in **Figure 19**.

The evolution of efficiency here given is based on the efficiency of the best commercial machine at a given time. This efficiency is referred to the maximum possible thermodynamically. Consequently steam engines efficiency refers not to

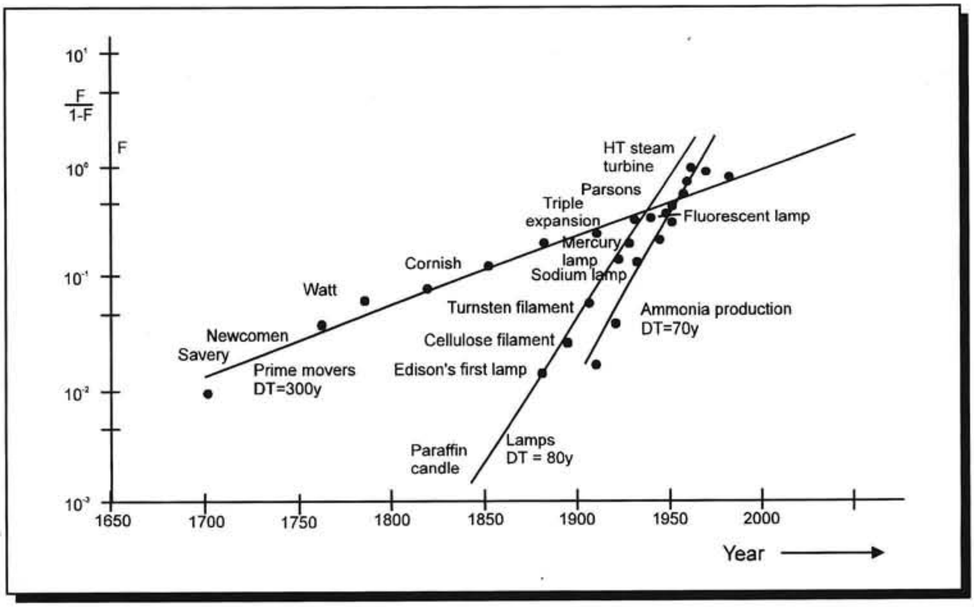


Figure 19: Thermodynamic efficiency

Carnot but to free energy in the fuel. The time constant Δt represents the slope given as the time to go from 10^2 to 10^0 or from 1% to 50% efficiency.

CHAPTER 10: INNOVATION IN SCIENCE AND TECHNOLOGY

Innovation is not confined to products or processes, but is also prominent in science. Theories about the properties and structure of the universe or the material world have changed dramatically over time, and the end to this process is not in sight. This Chapter will therefore discuss the work of Thomas S. Kuhn, *"The structure of Scientific Revolutions"*, and the more recent updates on the subject by J.L. Casti, titled *"Paradigms Lost"* .
Also in ship design methods innovation takes place; the way in which ships are calculated is changing radically, which is facilitated by the widespread availability of computers. This revolution in design methods is demonstrated with the help of American Bureau of Shipping's SafeHull System.

The insight in the historical development of science theories should give the engineer not only a sense of perspective, but also of assurance and self-confidence, in order to challenge conventional wisdom. Without this critical attitude, science can not progress and engineers should not be entitled to carry their title.
The first part of this Chapter is based on an excellent paper from J.A. Bell and J.F. Bell, titled *"Views of Knowledge and System Dynamics: A Historical Perspective and Commentary"* .

10.1 Views of knowledge

Science is based on views of knowledge; these in turn contain methodological theories - theories of how knowledge progresses - and epistemological theories - theories about the nature of knowledge. Methodological theories and epistemological theories are related to each other. There can be no complete understanding of how knowledge progresses without a discussion of what is to progress. Theories about the nature of knowledge always entail constraints on how it can be discovered and advanced.
Methodological theories help generate knowledge, legitimate ideas, render other ideas suspect, and propagate ideas to others. Each of the four functions - generation, legitimation, suspicion, and propagation - are illustrated by contrasting two well-known methodological views: induction and deduction.
Induction and *deduction* are the methodological components of *empiricism* and *rationalism*, respectively. The latter two terms refer directly to epistemological theories: knowledge consists of *facts* and knowledge consists of *ideas*.

The first function of methodological theories is to provide a formula for generating knowledge. The *inductivist*, as a first step is gaining knowledge, collects facts through observation. Only after exhaustively collecting empirical data will

he attempt to induce ideas from the facts, and even then he will be skeptical of his thought processes.
Unlike his opposite, the *deductivist* believes that the first stage in generating knowledge is to think. Knowledge is the jewel of precise and clear thoughts. Treating facts and observations with suspicion, he approaches them reluctantly, using them only to clarify his ideas. If there is conflict between the facts and his ideas, he tends to trust the latter.

The second function of methodological theories is to legitimate ideas. The inductivist claims legitimacy for his ideas because they are based on facts, and, therefore, he labels them *scientific*. The deductivist legitimates his ideas , not on the basis of empirical research, but on the precision of his thinking and the intrinsic clarity of his ideas. He, too, labels his ideas scientific. ***Each methodological theory accords scientific status to ideas that are legitimated by its own criterion!***

A consequence of the legitimating function is the third function of methodological theories: suspicion is created of ideas generated by or legimated by other methodological theories. Inductivists quickly attack ideas not thoroughly grounded in observation. Thinking is dangerous and extended contemplation is particularly debilitating. Deductivists, on the other hand, are unimpressed with inductivists claims to scientific status; facts are misleading, and ideas rooted in them are just as suspect.

One classic debate between inductivists followers of Newton and deductivist followers of Descartes provides an example of the difference in approach. Newtonians emphasised that there was a measurable force between masses - gravitation - and that the force was a fact. Whether the force acted through empty space or required an ether for its propagation was debated, but the fact that gravitation existed was beyond dispute. Cartesians, on the other hand, deduced that there could be no gravitational force from their thesis that all motion results from pushes. The *fact* of gravitation, which merited scientific status for the Newtonians, was rendered suspect by the deductions of the Cartesians.

Propagation is the fourth function of methodological theories. The inductivist mandate for propagation is quite simple: encourage everyone to observe facts. Books, reports and other presentations by inductivists begin with research findings. Conjectures and speculations are confined to a secondary role and appear, if at all, at the end. Even there, they are introduced by cautionary warnings and even apologies.
Deductivists propagate their ideas by invoking one's abilities to think clearly and draw conclusions validly. Like inductivists, they ask that preconceived ideas and prejudices be discarded. Their appeal, however, is to one's intuition and common sense, not to facts. Most deductivist books and reports commence with axioms followed by deductions. As a preamble there is sometimes an attack on

other ideas to show them unclear, inconsistent, or in conflict with intuition or common sense.

There are many other methodological theories besides inductivism and deductivism. The views of knowledge discussed here - inductvism, probabilism, instrumentalism, paradigmism, and refutationism - each has a methodological theory. Regardless of the particular methodological theory, however, the same four functions are served.

The first two functions, generation and legitimation of knowledge, are preeminent functions. They will be discussed further, on the basis of a historical overview, starting with Francis Bacon.

Francis Bacon's Revolution in Scientific Method

Francis Bacon (1561-1626), lord Chancellor under James I of England, distinguished himself in law, literature, politics, and philosophy. Perhaps his greatest contribution, however, was a new theory of how to seek and advance knowledge. The centres of learning in England during Bacon's era were universities, the strongholds of Catholic thought. Bacon condemned at the time Catholic theology and its Aristotelian roots in particular for stifling the growth of knowledge. In his works as *"Advancement of Learning"* (1605) and *"Novum Organum"* (1620) Bacon argued that natural philosophy - science - had progressed little since ancient times. He saw no merit in speculative philosophy, contending that in some respects modern thinkers knew less than the Greeks.
Not all modern men were lost to metaphysical speculation. Bacon admired the revolutionary discoveries of Copernicus and Galileo, marveled at the explorations of Marco Polo and Magellan, and appreciated such inventions as the printing press and gunpowder. Contrasting the lack of progress of speculative thinkers to the remarkable gains of others, Bacon posed himself a question: what demarcates speculative thinking from progressive thinking? His answer can be summarised in two parts.

First, lack of progress in the Catholic tradition was due to speculation about essences. Aristotelians believed that the universe consists of essences. Bacon contended that statements about essences reflect subjective belief and not objective reality. As a result, Aristotelian science amounted to idle conjectures about definitions and concepts, and Aristotelian ideas had reference to the real world only by accident. Progress could not be made by speculation.

Second, progress necessitated observation of material facts. The facts could not be related to Aritotelian intuitions. Instead, they would have to be located in the world outside ourselves, the physical reality. In sum, progress would be made by avoiding speculation and observing facts.

Bacon's methodological theory provides a legitimation for deciding which ideas are scientific and which are not. Since all scientific ideas must be inductions from facts, all scientific ideas must be reducible to facts. Ideas not reducible to facts are not legitimate. Since Bacon's time, methodological theories that assume that general ideas are generated from facts and/or are reducible to facts have been called *inductivist methodological theories*.

The crucial epistemological element in Bacon's view of knowledge is that knowledge is Truth, not speculation. His inductive method was a means of guaranteeing that Truth would be found, because if facts in the real world are beyond question, and scientific ideas are induced from facts, it follows that scientific ideas must also be beyond question, i.e., that scientific ideas are Truth.

Not just Aristotle and Bacon, but most philosophers and scientists up to the turn of the twentieth century believed that science is Truth. The view that science is not equal to Truth emerged since the early decades of the twentieth century with the overthrow of Newtonianism and the establishment of relativity theory and quantum principles.

Despite advantages over Aristotelian disputation, inductivism was severely criticised and its shortcomings exposed. The attacks were crucial for the development of probabilism, instrumentalism, and paradigmism.

Newton and Inductivism

Sixty-one years after Bacon died, Isaac Newton published his Mathematical Principles of *"Natural Philosophy"* (1687). It outlined a system of dynamics and celestial mechanics that were corroborated on all fronts. Almost everyone believed that Newton's physics was Truth. Further, Newton's success was credited to his adherence to inductive method.

Even before the publication of Newton's Mathematical Principles, Baconian method had received a most significant endorsement: The Royal Society of London had adopted it as the proper and official methodology for the advancement of knowledge. The Royal Society was an institution free of Catholic domination and this was believed to be crucial for the advancement of knowledge. Despite Newton's own reservations about the viability of Baconian induction, the public commonly believed that Newton had used induction.

Attacks on inductivism

Two profound critics during the era of Newtonian successes were David Hume (1711-1760) and William Whewel (1774-1866). Hume's attack provided the arguments that led to probabilism. Whewel's historical and psychological analyses, which were very similar to those of Thomas Kuhn over one century later, are behind another methodological theory: paradigmism.

Instrumentalism, although it did not evolve directly from inductivism, is indeed closely related and includes probabilistic methodology. Probabilism, paradigmism, and instrumentalism can thus be interpreted as outgrowths of the work of

Hume and Whewell. More specifically, all three methodological theories provide solutions to problems in inductivism that were created by an epistemological crises: the realisation that science is not Truth.

Initially David Hume, like nearly all his contemporaries, assumed that Newton's dynamics and celestial mechanics were Truth. He also assumed that the inductive method had delivered the dynamics and celestial mechanics. After comparing these two assumptions, however, he found them inconsistent. When Hume's *"A Treatise of Human Nature"* was published in 1739, intellectuals gave it a very cold reception, as his attacks threw doubt on two most cherished beliefs: the Truth of Newtonian physics and the validity of inductive method.
Hume argued that Newtonian physics presupposes a universal law of causality: for every event there is a cause. But, his reasoning continued, no one can be sure that in the future the same causes will lead to the same effects, or *facts*.
Hence future facts can only be inferred with a degree of probability. Hume concluded that (1) either Newtonian physics, if it originated in and is legitimated by inductive method, cannot be True knowledge; it can be highly probable at best; (2) or inductive method is not entirely valid; (3) or both (1) and (2).

Hume did make a hesitant choice between the two pillar beliefs. He put his faith in the inductive method and, at the same time, declared Newtonian physics highly probable.
The view of knowledge attached to Baconian induction had changed forever after Hume's analysis. The crucial epistemological element of Baconian induction - that knowledge is Truth - could not be supported. Hume's attack led to a fallback position of inductivism: facts can generate ideas that are probable, but not certain; legitimate ideas are reducible - within a reasonable degree of probability - to the facts. Inductivism had given birth to *probabilism*.

Nearly one century after Hume's attack, William Whewell put forth historical and psychological arguments against inductivism. His major essays, *"History of the Inductive Sciences"* (1837) and *"Philosophy of the Inductive Sciences"* (1840) set forth unpopular theses.
In his studies of the history of science and psychology of discovery, Whewell found that the processes of advancement did not resemble the research and induction stages prescribed by inductivism. Scientists, he found, made bold guesses and then tested them against facts. Most of the guesses turned out be mistaken, but a few were correct. Even correct ideas could not be proclaimed the Truth; they very well might be mistaken later.
Whewell argued that freedom in thinking and a vivid imagination were important elements in the guessing and the testing. Although facts seemed unimportant for generating knowledge, Whewell did maintain that they are significant for legitimating knowledge. When an idea had helped a scientist understand phenomena, he would then deduce the pertinent facts to confirm the idea. If the facts were there as expected, the idea would be legitimate.

Whewell's challenge to Baconian induction was clear: inductive method could not adequately explain either the generation or the legitimation of knowledge. On the other hand, his view of knowledge shared with probabilism the epistemological thesis that knowledge is not Thruth and it provided another solution to the crisis created by that epistemological thesis.
Whewell's view of knowledge is very similar to an interpretation of Thomas Kuhn's view of knowledge; the name of Whewell should therefore be associated with the founding of paradigmism.

Probability theory

Although Hume's *"A Treatise of Human Nature"* was received without enthusiasm in 1739, the situation in 1763 changed radically with the publication of Thomas Bayes' *"Essay Towards Solving a Problem in the Doctrine of Chances"*. To calculate the probability of a given outcome based on prior knowledge, one needs to know - or at least assign - the prior probabilities; that is, the probabilities before the trials are made. To this day the label *Bayesian* implies the use of prior probabilities in the calculation of probabilistic statements.
Bayesians, from the time of their namesake to the present day, have been confronted with two major difficulties: deciding which constituent factors affect a certain outcome and assigning prior probabilities to those factors. These difficulties constrain the problem-solving power of the probabilistic methodology.
The probabilistic theory was at the basis of Einstein's work on the theories of relativity to explain the macro-universe during the early decades of this century, and later on the micro-universe of quantum mechanics. Probabilism as a method took strong hold; the ultimate matter of the universe appeared to operate according to its principles.
Had probabilism developed as a tool for working only on specific types of problems, it might not have developed into a cult. But probabilism suffered the same fate as inductivism. In the same way that Newtonian physics fostered and protected inductivism, the success of quantum mechanics fostered and protected probabilism. Ironically, Einstein never did surrender to the probabilistic view, even though his own work in applied probability theory had been a major factor in its development.

An instrumentalist view of knowledge

Instrumentalists maintain that knowledge progresses by formulating broader and broader formulas to incorporate more and more data, but that those formulas are merely conventions - they make no claims about the real world. For the instrumentalists theories and hypotheses did not have be true, as long as they could produce calculations that agree with observations.
Unlike probabilism and paradigmism, instrumentalism was not a direct historical outgrowth of inductivism. It did so happen, however, that the Heisenberg un-

certainty principle provided a reason to interpret probabilistic equations positivally, and a flood of instrumentalism was the result.

10.2 Paradigmism: Thomas Kuhn's view of knowledge

John Casti in *"Paradigms Lost"*, recounts the process that led Thomas Kuhn to his formulation of the paradigm view of knowledge.

In 1947 Kuhn, a young professor at Harvard, was asked to organise a set of lectures on the origins of seventeenth-century mechanics. As preparation, he began tracing the subject back to its roots in Aristotle's *Physics*, being struck time and again by the total and complete wrongheadedness of Aristotle's ideas. Aristotle held that all matter was composed of spirit, form, and qualities, the qualities being air, earth, fire and water. Kuhn wondered how such a brilliant and deep thinker, a man who had singlehandedly invented the deductive method, could have been so flatly wrong about so many things involving the nature of the physical world. Then as Kuhn recounts it, one hot summer day the answer came to him in a flash while he was poring over ancient texts in the library: Look at the universe through Aristotle's eyes!
Instead of trying to squeeze Aristotle's view of things into a modern framework of atoms, molecules, quantum levels, and so forth, put yourself in Aristotle's position, give yourself the prevailing world view of Aristotle's time, and all will be light. For instance, if you adopt Aristotle's world view, one of the presuppositions is that every body seeks the location where by its nature it belongs. With this presumption, what could be more natural than to think of material bodies as having spirits, so that 'heavenly' bodies of air like quality rise, while the spirit of 'earthly' bodies causes them to fall?
This stroke of inspiration resulted in Kuhn's developing the idea that every scientist works within a distinctive paradigm, a kind of intellectual Gestalt that colors the way Nature is perceived. The situation is vaguely analogous to the picture in **Figure 1**, where one way of looking shows what appears to be two men face to face in profile, while another way shows a flower vase.

According to Kuhn's thesis as presented in his enormously influential 1962 book *"The Structure of Scientific Revolutions"*, scientists, just like the rest of humanity, carry out their day-to-day affairs within a framework of presuppositions about what constitutes a problem, a solution, and a method. Such a background of shared assumptions makes up a paradigm, and at any given time a particular scientific community will have a prevailing paradigm that shapes and directs work in the field. Since people become so attached to their paradigms, Kuhn claims that scientific revolutions involve bloodshed on the same order of magnitude as that commonly seen in political revolutions, the only difference being that the blood is now intellectual rather than liquid - but no less real!

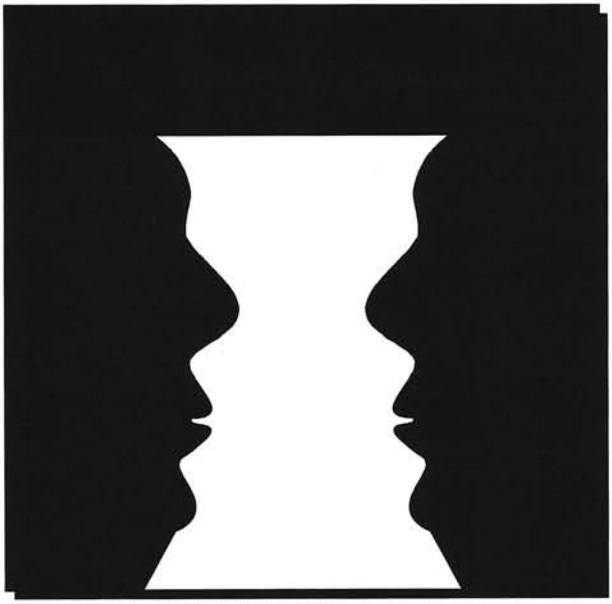


Figure 1: Two visual gestalts or 'paradigms'

The concept of paradigm is not very well defined by Kuhn, but Casti illustrates it with the help of the following map-making analogy. Let us imagine scientific knowledge of the world as being the terra incognita of the ancient geographers and map makers. In this context, a paradigm can be thought of as a crude sort of map in which territories are outlined, but not too accurately, with only major landmarks like large rivers, prominent mountains, and the like appearing. From time to time, explorers venture into this ill-defined territory and come back with accounts of native villages, desert regions, minor rivers, and so on, which are then dutifully entered on the map. Often such new information is inconsistent with what was reported from earlier expeditions, so it is periodically necessary to redraw the map totally in accordance with the current best estimate of how things stand in the unknown territory. Furthermore, there is not just one map maker but many, each with a different set of sources and data on the lie of the land. As a result there are a number of competing maps of the same region, and the adventurous explorer has to make a choice of which map he will believe before embarking upon an expedition to the New World. Generally, the explorer will choose the old, reliable firm of map makers, at least until gossip and reports from the Explorers Society show too many discrepancies between the standard maps and what has actually been observed. As these discrepancies accumulate, eventually the explorers shift their allegiance to a new firm of map makers whose pictures of the territory seem more in line with the reports of the returning adventurers.

This exploration fable gives a fair picture of the birth and death of scientific paradigm. Kuhn realised that revolutionary changes in science overturning old theories are not in fact the normal process of science, nor do theories start small and grow more and more general as claimed by Bacon, nor can they ever be axiomatised as asserted by Newton. Rather, for most scientists major paradigms are like a pair of spectacles that they put on in order to solve puzzles. Occasionally a paradigm shift takes place when the spectacles get smashed, and they then put on a new pair that transforms everything into new shapes, sizes, and colors. Once this shift takes place, a new generation of scientists is brought up wearing the new glasses and accepting the new vision of Truth. Through these new glasses, scientists see a whole new set of puzzles to be solved in the process of carrying out what Kuhn called *normal science*.
The paradigms have great practical value for the scientist just as maps have value for the explorer: without them no one would know where to look or how to plan an experiment (expedition) and collect data. This observation brings out the crucial point that there is no such thing as an *empirical* observation or fact; we always see by interpretation, and the interpretation we use is given by the prevailing paradigm of the moment. In other words, the observations and experiments of science are made on the basis of theories and hypotheses contained within the prevailing paradigm. As Einstein put it, "*The theory [read paradigm] tells you what you can observe*".
According to Kuhn's paradigmatic view of scientific activity, the job of normal science is to fill in the gaps in the map given by the current paradigm, and it is only seldom, and with great difficulty, that the map gets redrawn when the normal scientists (explorers) turn up so much data not fitting into the old map that the map begins to collapse into morass of inconsistencies.

Thomas Kuhn's *"The Structure of Scientific Revolutions"* contains a new, or according to some old (Whewell) view of knowledge, summarised in the concept of paradigm, as discussed above. Most of Kuhn's methodological theses parallel those of Whewell. They are the following:

- That science grows by imaginative new ideas that are then used to search out facts;
- That facts are only seen in light of these ideas; research is directed to uncover the facts;
- That scientists try to collegiate ideas into a unit;
- That there is a strong tendency to force the world to fit one's ideas;
- That rough comparisons of the legitimacy of competing ideas can be made by measuring them against nature; the comparison often leads to the separation of mistaken ideas from other ideas in a unit.

The concept of paradigm has achieved a large following in modern science, as it created a platform for scientists to discuss their pre-scientific assumptions about their particular field of expertise explicitly and it facilitated a less biased discussion amongst them.

The reasons why Kuhn's view of knowledge achieved such an inroads in the scientific community at the expense of other views, was based on a number of criteria:

- *Problem-solving power*. The *types* of problem for which a view of knowledge can generate fruitful solutions should be considered. The importance of those problems should be weighed, as well as the range of problems for which a view of knowledge is useful.
- *Theoretical progressivity*. Any view of knowledge will render formulas for generating and legitimating knowledge that we know. What is desired, however, are views of knowledge that will generate and legitimate ideas that are likely to lead to new - often unforeseen - insights.

Paradigm shift

Paradigms are the views of the world held by a large group of peers within a certain discipline of science and these are constantly subject to change. This is called the *paradigm-shift*. This process can be compared and linked to the S-curve theory discussed in previous chapters. The awareness that scientific theory is governed by paradigms and subject to shifts, is more or less equivalent at the micro-level to the existence of S-curves and shifts within the disciplines that are covered by the paradigms.

How does this S-curve relate to the paradigm discussed before? A paradigm also follows a pattern, a sort of performance and/or life cycle. Paradigms may parish and shift to new paradigms. A paradigm shift is to be expected within a certain scientific field, when phenomena remain unsolved, in spite of the considerable effort put into solving the puzzle. Apparently, the current paradigm is not good enough to achieve the last link discovery. Thomas Kuhn describes in The Structure of Scientific Revolutions many examples of scientific discoveries and what preceded the long journey that led to the discovery of the 'truth'. The process of scientific discovery and the development of theories about the reality goes with leaps and bounds and resembles very closely the process of paradigm-shifts.
Figure 2 shows the relationship between the paradigm-shifts at the macro and the S-curve shifts at the micro level. A good scientific paradigm will stimulate the search for innovative ways to improve the performance of theories, but also of products and processes.

John L. Casti 's *"Paradigms Lost; images of man in the mirror of science"* contains a number of studies on science themes in which there does not yet exist a shared view of reality (paradigm), and where paradigms will change and be lost. The believe systems (paradigms) that are discussed by Casti range from the origin of life (physical and biochemical processes) on earth, to the believe that digital computers can in principle think.
The benefit of his work is that it makes us clear that scientific paradigms are not cast in iron. They are subject to change, and that is the important message of

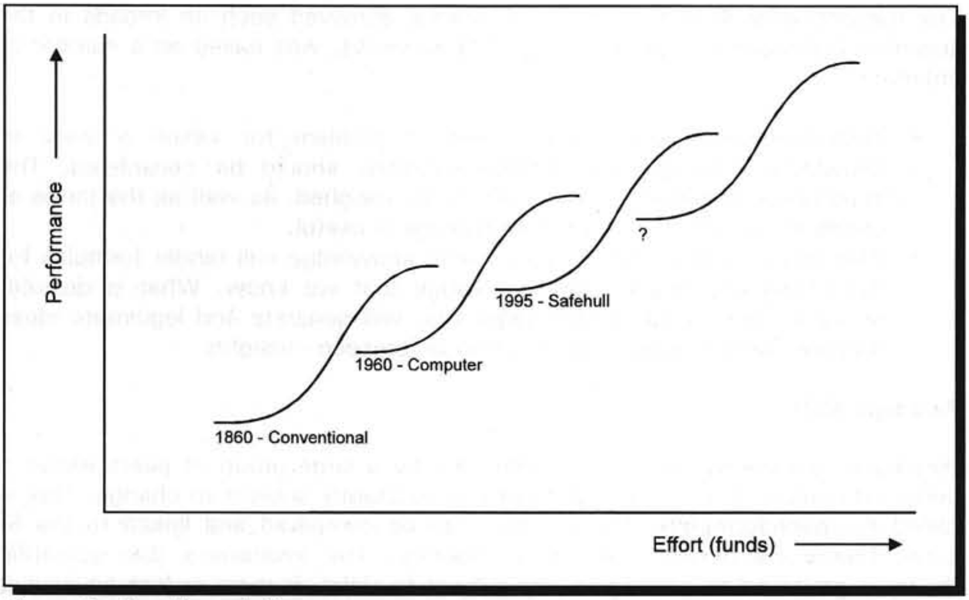


Figure 2: Paradigm shift

this Chapter.
The arrogance of scientist about the completeness of their paradigm is nicely illustrated by the case of biologists; this science has identified and classed some 1.6 million species, which seems a phenomenal figure. However, it is estimated that some 100 million more species exist on earth that have not been discovered; their discovery may change our perception of the global biodiversity and consequently our mental model and paradigm of the reality.

How is the subject of paradigm shift related to the subject of the book *"Design Innovation in Shipping"*? That will be illustrated with the help of a design-paradigm shift that is taking place in shipping: the introduction of new methods like the ABS SafeHull System.

10.3 Classification of ships

Initial systematic assessment of the design, equipment and condition of the ships was undertaken in the eighteenth century. Already in 1764 in London, the first ship's register was published by underwriters and brokers, containing details of the condition of the registered ships.
In particular marine insurers and shippers were interested in the availability of a reliable and objective assessment of the condition of a ship for which they had to evaluate the risk of insurance or to which they were to entrust their cargo.

This called for independent, impartial and objective technical organisations to assess the ships with respect to their seaworthiness, their classification and their technical supervision. From this, the technical supervisory organisations derived their name, Classification Society.

Classification meant that ships were sorted according to their design, condition and age into different classes. In addition, the Classification Society issued and continued the issue of a register, in which the main features (dimensions, year of built, etc.), the date of the latest inspection, the period of class, etc. are visible to all. They publish construction rules, conduct tests on ships, etc. The technical supervision of ships was a private initiative and the technical rules and regulations for the promotion of safety existed on a private basis prior to the introduction of laws to this effect.
This section, taken from the book published by Germanischer Lloyd (GL) on the occasion of its 125th anniversary in 1992, is concluded with some remarks about the construction rules.

The first GL Construction Rules for wooden ships were published in the very year of its establishment (1867) and were exemplary for international classification work. For the first time, the scantlings of the structural elements were not dimensioned according to the tonnage of the ship, as had been the practice of Classification Societies up to that time, but depended on the main dimensions of length, breadth and depth. This ensured that the important ratio of depth to breadth of the ship as well as depth to length were considered in the determination of the strength of the main structural elements.
The construction rules were also being constantly revised and adapted to progress in technology. This resulted, among others, in the publication of rules for electric lighting, for the construction of machinery and boilers, for testing of wrought iron and mild steel.

Only in recent times, between 1960 and 1970, led the use of large computers to the gradual replacement of empirical data on which the construction rules had previously been based, by scientifically based systems of calculation. The technical capabilities later on led to the use of the Finite Element method, which again resulted in revolutionary developments in shipbuilding.
The progress in ship design techniques is again experiencing a revolution, now started by the American classification society American Bureau of Shipping (ABS). Their SafeHull System and the implications for naval architectural science will be discussed now.

ABS SafeHull System

The way ships were built and designed until the 1970s was essentially an evolutionary process without dramatic changes in configuration or size. Most importantly, mild steels were predominant in ship construction through that time. It was therefore relatively easy for classification societies to develop their strength

criteria. These are based on practical experience gained over the years and have been typically presented in a semi-empirical type format, with easy to use tables and formulations.
However, the evolutionary approach to development changed in the 1970s with the introduction of VLCCs, ULCCs, large bulk carriers and big container ships. Apart from a dramatic increase in size, structural configurations have also changed. A recent example is the introduction of the double hull tankers, and the increasing use of high tensile steel. In addition, the requirements of the International Conferences on MARPOL 1973 and Tanker Safety and Pollution Prevention, 1978 had a significant impact on the design of tankers. One of the results was deeper ships, allowing thinner deck and bottom scantlings.

An important ramification of these changes is the effect they have on the failure modes of the hull structure that impact on safety. Many modern design features fall outside the experience base of the existing strength criteria. As a result, the traditional primary structural failure mode of yielding, has been augmented by the modes of buckling and fatigue in influencing the design. Buckling and fatigue can no longer be assumed to be accounted for via implied safety margins of the existing criteria. As there was no consistent and rational basis for extending the existing criteria into these new areas, a new basis had to be established.
This meant that a new and more scientific approach was required to develop the strength of ship structures, accounting for these failure modes in a comprehensive, realistic way. The major change that ABS applied in its Rules was the calculation based on engineering first principles. The back-to-the-basics approach required first the establishment of the dynamic loads and the combination of these loads, acting on both the global and local structures within the hull girder. The further process, which ABS has packaged in the SafeHull Software System, is schematically shown in **Figure 3** and **Figure 4**.

The first application of the SafeHull System was on oil tankers, while the application on bulk carriers and container ships is in advanced phase of development. In 1994, the ABS rules for the design of large tankers had been replaced by the SafeHull Software System. This is a rather unique event, which marks the start of a new area in the science of ship design. ABS illustrates this change itself with **Figure 5**, in which it shows the evolution of ship structures design.

From a more academic point of view, this development can be placed in the framework of the paradigm shift, as demonstrated in Kuhn's *"The Structure of Scientific Revolutions"*. The SafeHull approach presents a new, holistic approach to ship design, in which not only structural strength and fatigue during the life of the ship are assessed, but also the wasting of the ship's hull through corrosion and its consequences on this strength.
In the ABS brochure on the SafeHull System, the last chapter is devoted to the future. ABS believes strongly that the current revolution as represented by the dynamic load calculation, the strength calculation, including fatigue and corrosion, is not the ultimate destination of the naval architects and maritime

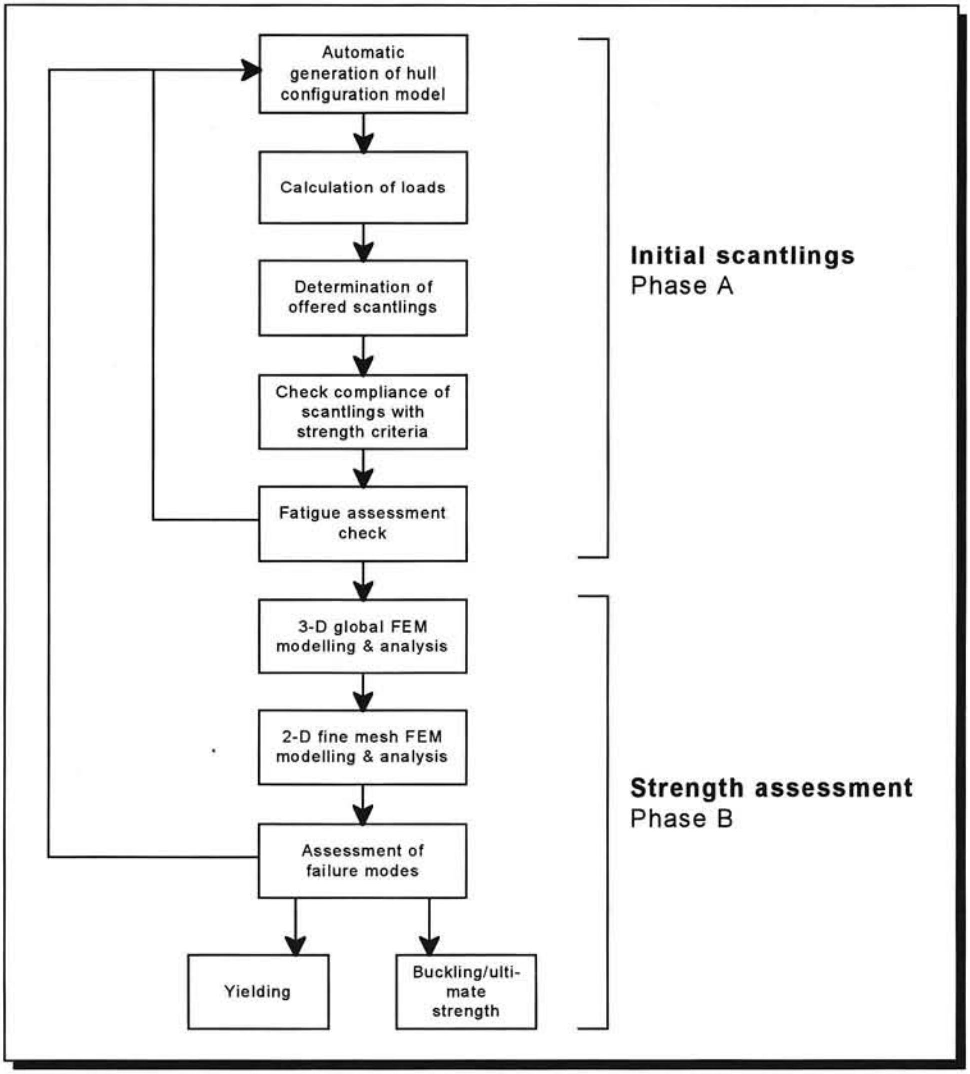


Figure 3: ABS SafeHull software system

engineers. The next big step is - according to ABS - the application of reliability based methods to the design and evaluation of ship structures. This will be a natural follow-up to SafeHull, some aspects of which are based on probabilistic methods.

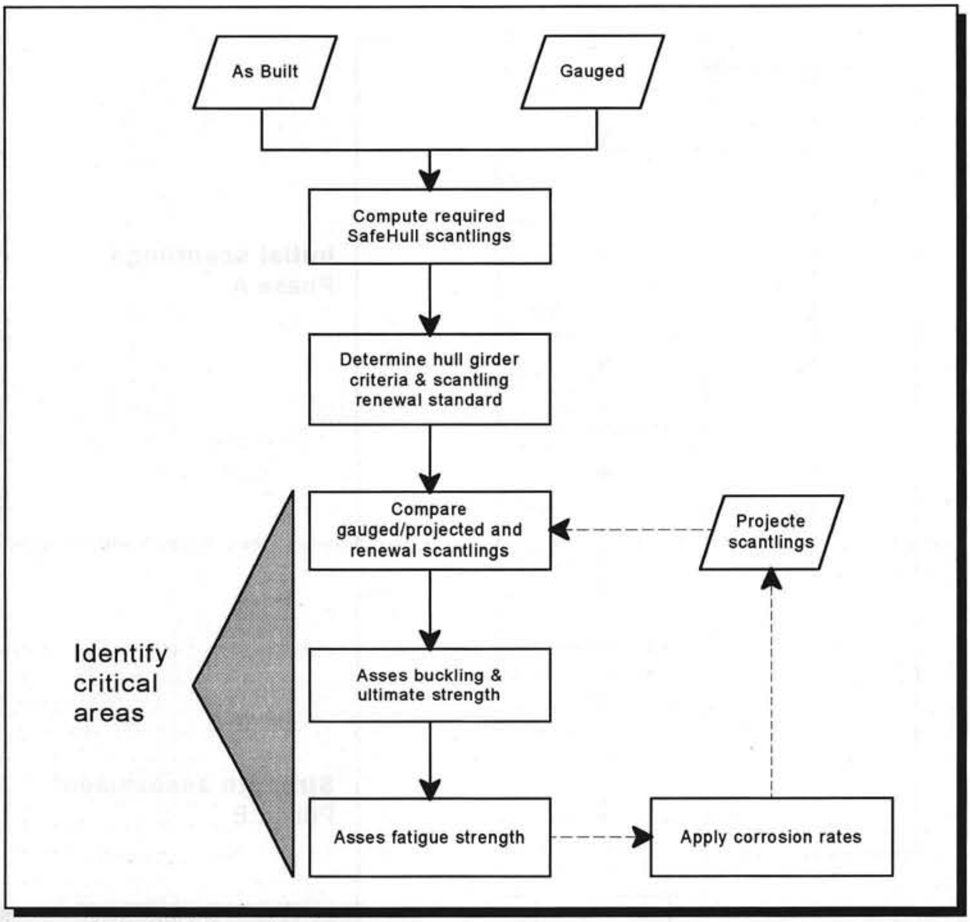


Figure 4: SafeHull evaluation

10.4 Paradigm shift ship design

From the first systematic rules for the design of ships developed by Germanischer Lloyd in 1867 to the American Bureau of Shipping SafeHull Rules System of 1992, covers a period of some 125 years in which the design and calculation of ships has dramatically changed and improved. These 125 years can be schematically divided into three periods of scientific (paradigm) change. The first period started actually by the underwriters (later Lloyd's) around 1750 and was formalised around 1867 by the issuing of the GL-rules; nothing much changed in the engineering approach, which was based on practical experience and some engineering principles. This lasted very long, as there was no alternative available.

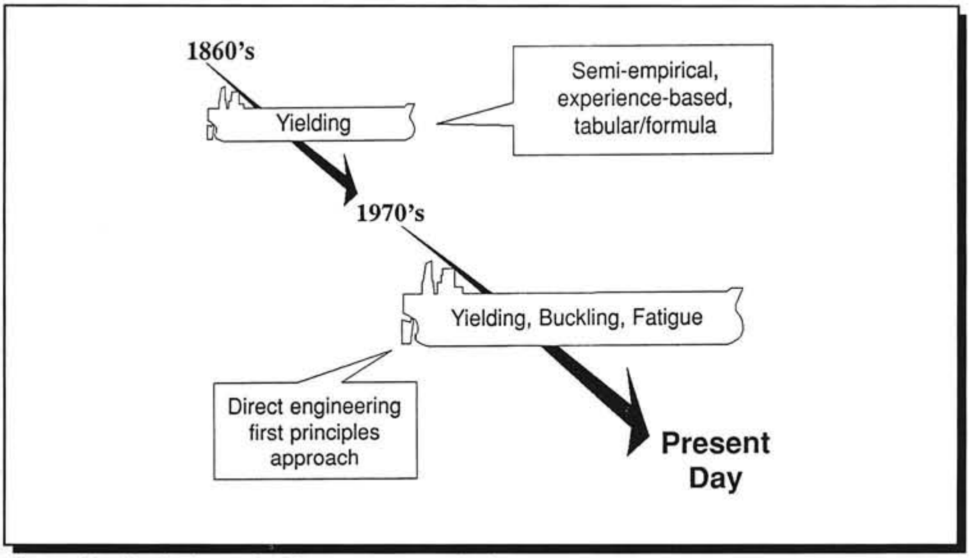


Figure 5: Evolution of ship structures design

That came with the introduction of the computer in the industry in the early 1960s. This facilitated calculations of a more complex nature, such as the finite element method. This period of transition lasted until 1992, when ABS introduced its holistic SafeHull approach. Other classification societies have followed this initiative since, which only underlines the strength of the change.

The consortium of Bureau Veritas, Germanischer Lloyd and Registro Italiano Navale, under the name Unitas, has put forward yet another approach to improve the classification service during the life cycle of the ship. This approach, called *On Line Class System*, is illustrated in **Figure 6**. Unitas described the new system as follows.

Traditional classification provides rules for the design, construction and service phase. Verification of the ship's condition at fixed intervals assess compliance with the rules at the moment of survey. This is the instantaneous picture approach.

Whilst keeping the traditional classification unchanged, an additional concept is introduced in order to review each ship's particular history, her actual condition and likely evolution on a systematic basis, with the objective to promote the prevention of risks still further.

This approach is further enhanced by an information technology, which makes it easy for the user to access data on the ship's characteristics, such as the original design and construction data, the in-service survey data and the possibility to collect data from hull stress sensors. This latter programme is called STAR, which stands for System of Traceability and Analysis of Records.

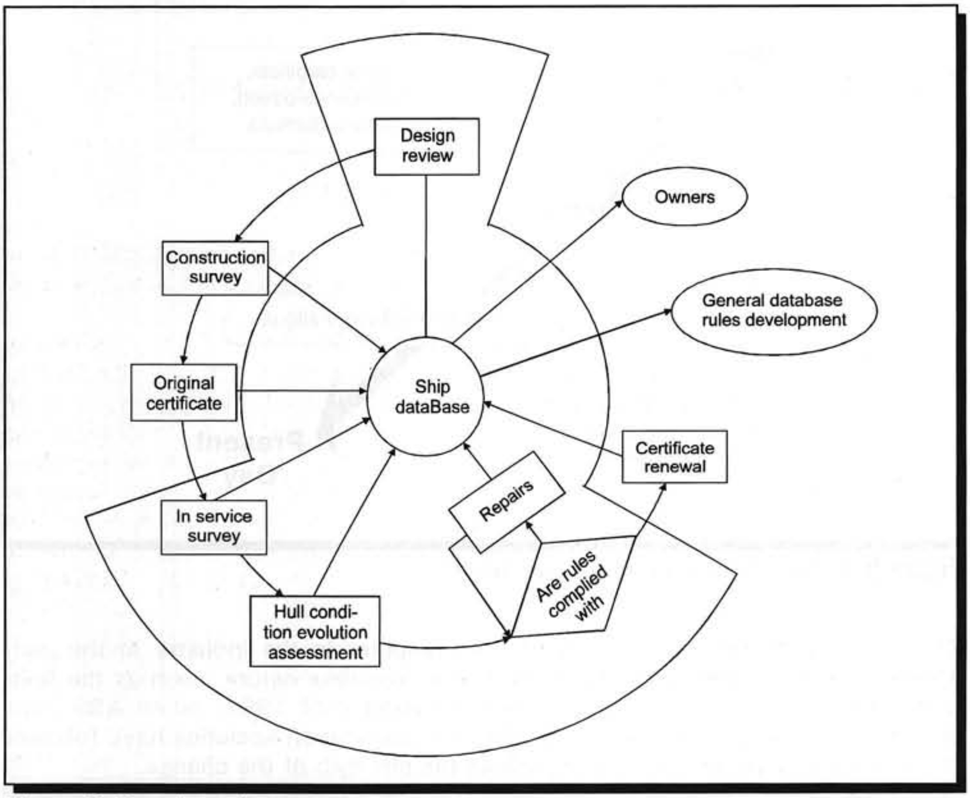


Figure 6: One line class system

The On Line Class System is used in conjunction with the *Rational Ship Design* method, which is in its structuring of the ship design process, more or less similar as the SafeHull approach.

It will probably take at least a decade before the SafeHull Rational Ship Design approaches are developed for all the major ship types, and that the users have become familiar with the potential. It is challenging to know, especially for the academic community, which has completely missed the development of the holistic design concept like SafeHull, that ABS already prepares the fourth generation of design tools, based on advanced reliability methods. Innovation, also in applied science, never stops. This time around universities should be at the forefront to co-develop these innovations!

CHAPTER 11: INNOVATION AND THE FIRM

11.1 Innovation and environmental turbulance

Innovation can be a goal in itself, but it is usually triggered by the competitive forces in the business environment of firms. The need for innovation can thus be related to the changes in the competitive environment.
In the past, the speed of change has been relatively slow, and the competitive environment could be characterised as stable. Over the last century, the pace of change has increased drastically in many sectors and this resulted not only in the global economy as we know it today, but also in a dramatic change in the turbulence level of the competitive environment. Igor Ansoff, the management scientist, has developed a concise diagram of the change in turbulence level and the consequences for the evolution of management systems within firms, see **Table I**. This diagram was originally published in his 1965 book *"Corporate Strategy"*, and is now part of his broader vision on strategy, *"Implanting Strategic Management"* (1990).

As shown in the figure, the systems can be grouped into four distinctive stages of evolution:

1. Management by (after the fact) control of performance, which was adequate when change was slow;
2. Management by extrapolation, when change accelerated, but the future could be predicted by extrapolation of the past;
3. Management by anticipation, when discontinuities began to appear but change, while rapid, was still slow enough to permit timely anticipation and response;
4. Management trough flexible/rapid response, which is currently emerging, under conditions in which many significant challenges develop too rapidly to permit timely anticipation.

Strategic success hypothesis

Strategic diagnosis is a systematic approach to determine the changes that have to be made to a firm's strategy and its internal capability in order to assure the firm's success in its future environment. The diagnostic procedure is derived from the strategic success hypothesis that Ansoff based and validated on empirical research. This hypothesis states that the performance potential is optimum when the following three conditions are met:

Changeability	1900	1930	1950	1970	1990
Unpredictability of the future	**Familiar**		**Extrapolable**	**Familiar discontinuity**	**Novel discontinuity**
Recurring	* Systems & procedures manuals * Financial control				**Management by control**
Forecastable by extrapolation	* Operation budgeting * Capital budgeting * Management by objectives * Long range planning				**Management by extrapolation**
Predictable threats and opportunities		**Management by anticipation of change**		* Periodic strategic planning * Strategic posture management	
Partially predictable opportunities Unpredictable surprises		**Management by flexible/ rapid response**		* Contingency planning * Strategic issue management * Weak signal issue manag. * Surprise management	
Turbulence level	1 Stable	2 Reactive	3 Anticipating	4 Exploring	5 Creative

Table I: Evolution of management systems

1. Aggressiveness of the firm's strategic behaviour matches the turbulence of its environment.
2. Responsiveness of the firm's capability matches the aggressiveness of its strategy.
3. The components of the firm's capability must be supportive of one another.

In this context three concepts will be further described: environmental turbulence, strategic aggressiveness and organisational responsiveness.

Environmental turbulence is a combined measure of the changeability and predictability of the firm's environment. Its main characteristics are:

- Changeability; the complexity of the firm's environment and the novelty (familiarity) of the successive challenges that the firm encounters in the environment;
- Predictability; rapidity of change is the ratio of the speed with which challenges evolve in the environment to the speed of the firm's response

and the visibility of the future that assesses the adequacy and the timeliness of information about the future.

A scale of environmental turbulence is shown in **Table II**. Level 1 turbulence (a placid environment) is rarely observable in so-called free market economies in which natural forces of competition are at work. The reason is that the key to success in today's competitive environment is continual substitution of new products and services that are superior to the historical products and services. *Firms that do not innovate, do not survive*. At a turbulence level of 4 and above, active concern with strategic management becomes vital to the firm's success and even its survival.

Environmental turbulence	Repetitive	Expanding	Changing	Discontinuous	Surprising
Complexity	National Economic	+	Regional Technological	+	Global Socio-political
Familiarity of events	Familiar	Extrapolable		Discontinuous Tamiliar	Discontinuous Novel
Rapidity of change	Slower than response		Comparable to response		Faster than response
Visibility of future	Recurring	Forecastable	Predictable	Partially predicable	Unpredictable surprises
Turbulence level	1	2	3	4	5

Table II: Turbulence scale

Strategic aggressiveness is described by two characteristics:

- The degree of discontinuity from the past of the firm's products/services, competitive environments, and marketing strategies. The scale of discontinuity ranges from no change to incremental change, to change that is discontinuous for the firm but observable in the environment, to creative change that has not been observed previously.
- Timeliness of introduction of the firm's new products/services relative to new products/services that have appeared on the market. Timeliness ranges from reactive to anticipatory, to innovative, to creative.

Table III describes the appropriate strategic aggressiveness that, according to the strategic success hypothesis, is necessary for the success at each turbulence level. *Level 1* aggressiveness is rarely observed in business environment, but is common in the nonprofit organisations that do not change their products/services unless forced by a threat to their survival. On *level 2*, on which the environment changes slowly and incrementally, a firm succeeds if it changes its products only in response to competitors' moves. In the absence of threats from competition, such firms stick to their historical products/services, while minimising costs and underpricing competition. On *level 3* the successful firms progressively improve their historical products/services in anticipation of the evolving needs of the customers. *Level 4* aggressiveness is observed in firms whose environment is subject to frequent discontinuities and poor predictability. At this level, aggressiveness is more complex than on the other levels, and this is even more so at the *level 5*. To remain a leader in developing products/services the firm must incorporate the cutting edge of innovation and technology.

Environmental turbulence	**Repetitive** Repetitive	**Expanding** Slow Incremental	**Changing** Fast Iincremental	**Discontinuous** Discontinuous Predictable	**Surprising** Discontinuous Unpredictable
Strategic aggressiveness	**Stable** Based on precedents	**Reactive** Incremental Based on experience	**Anticipatory** Incremental Based on extrapolation	**Entrepreneurial** Discontinuous Based on expected future	**Creative** Discontinuous Based on creativity
Turbulence level	1	2	3	4	5

Table III: Matching agressiveness to turbulence

In addition to strategic aggressiveness, the responsiveness of the firm's organisational capability must also be matched to the environmental turbulence. **Table IV** shows the responsiveness appropriate to different turbulence levels.

On *level 1*, where the environment is repetitive and the optimal strategic behaviour is change-rejecting, the optimal organisation suppresses strategic change. The organisation is highly structured with hierarchical, centralised authority.

On *level 2* the efficiency-driven firm permits strategic change to occur, but only after operating management has failed to meet the firm's goals. The organisation is introvert, focussed on internal efficiency and productivity. Little attention is paid to the environment since it is assumed that minimisation of costs will automatically assure success in the marketplace. The power centre is usually in the production function. As a result, efficiency-driven firms are frequently referred to as production-driven.

Successful market-driven firms on *level 3* are extroverted and future oriented. The focus is on serving the future needs of the firm's historical customers, using the historical strengths of the firm.

A distinct characteristic of an environment-driven firm on *level 4* is that, unlike the market-driven firm, it has no attachment to history. Future validity of historical success strategies is continually challenged and so is the future attractiveness of historically attractive markets.

The environment-creating firms on *level 5* have a feature in common with efficiency and market-driven firms; all three are usually driven by a single function. On level 4 this may be a creative market development function or a creative R&D department. A characteristic that distinguishes an environment-creating firm from production- or market-driven firms is its total commitment to creativity. The past is recognised only as something not be repeated!

	Repetitive	**Expanding**	**Changing**	**Discontinuous**	**Surprising**
Environmental turbulence	Repetitive	Slow Incremental	Fast Iincremental	Discontinuous Predictable	Discontinuous Unpredictable
	Stable	**Reactive**	**Anticipatory**	**Entrepreneurial**	**Creative**
Strategic aggressiveness	Based on precedents	Incremental Based on experience	Incremental Based on extrapolation	Discontinuous Based on expected future	Discontinuous Based on creativity
Turbulence level	1	2	3	4	5

Table IV: Matching responsiveness to turbulence

The three concepts environmental turbulence, strategic aggressiveness and organisational responsiveness are summarised in **Table V**.

Thriving on chaos

The book *"In search of excellence"* , by T. Peters and R.H. Waterman started the debate on the characteristics that made firms excel in the marketplace. Tom Peters published follow-up books, titled *"A passion for Excellence"*, and *"Thriving on Chaos"*. The latter book is a plea for the acceptance by companies of a continuous high level of turbulence in the business environment and consequently that they adapt themselves to this new reality. In fact, Peters states that the world has become a global marketplace, where one factor is constant, and that is Change! This corresponds with the concept of environmental turbulence as defined by I. Ansoff. The business environments edges towards a level 5 turbulence and firms better accept the consequences and restructure themselves accordingly.

	Repetitive	Expanding	Changing	Discontinuous	Surprising
Environmental turbulence	Repetitive	Slow Incremental	Fast lincremental	Discontinuous Predictable	Discontinuous Unpredictable
	Stable	**Reactive**	**Anticipatory**	**Entrepreneurial**	**Creative**
Strategic aggressiveness	Based on precedents	Incremental Based on experience	Incremental Based on extrapolation	Discontinuous Based on expected future	Discontinuous Based on creativity
	Custodial	**Production**	**Marketing**	**Strategic**	**Flexible**
Responsiveness of capability	Suppresses change	Adapts to change	Seeks familiar change	Seeks new change	Seeks novel change
Turbulence level	1	2	3	4	5

Table V: Matching triplest that optimise a firm's ROI

The winners of tomorrow will deal proactively with chaos, not as a problem to be got around. Chaos and uncertainty are market opportunities for the wise, contends Peters. The successful firm in this turbulent environment, will be:

- Flatter, have fewer layers of organisation structure;
- Populated by more autonomous units with more decentralised authority;
- Oriented towards differentiation, producing high value-added goods, services that create niche-markets;
- Quality conscious, service-conscious and more responsive;
- Much faster at innovation, and a user of highly trained, flexible people as the principle means of adding value.

In **Chapter 12**, Peters' recipy for pursuing fast-paced innovation will be discussed in more detail.

Turbulence in the freight markets

Turbulence or volatility is a basic characteristic of the maritime sector. This is clearly illustrated by the development of the freight markets of oil tankers and bulk carriers. **Figure 1** shows the development of the freight markets over the period 1947-1987 taken from M. Stopford's *"Maritime Economics"*.

The rollercoaster movement of freight rates and the corresponding causes during extreme rate level movement - mostly wars - make it clear that shipping, at least liquid and dry bulk shipping, is constantly exposed to chaos. The shipping com-

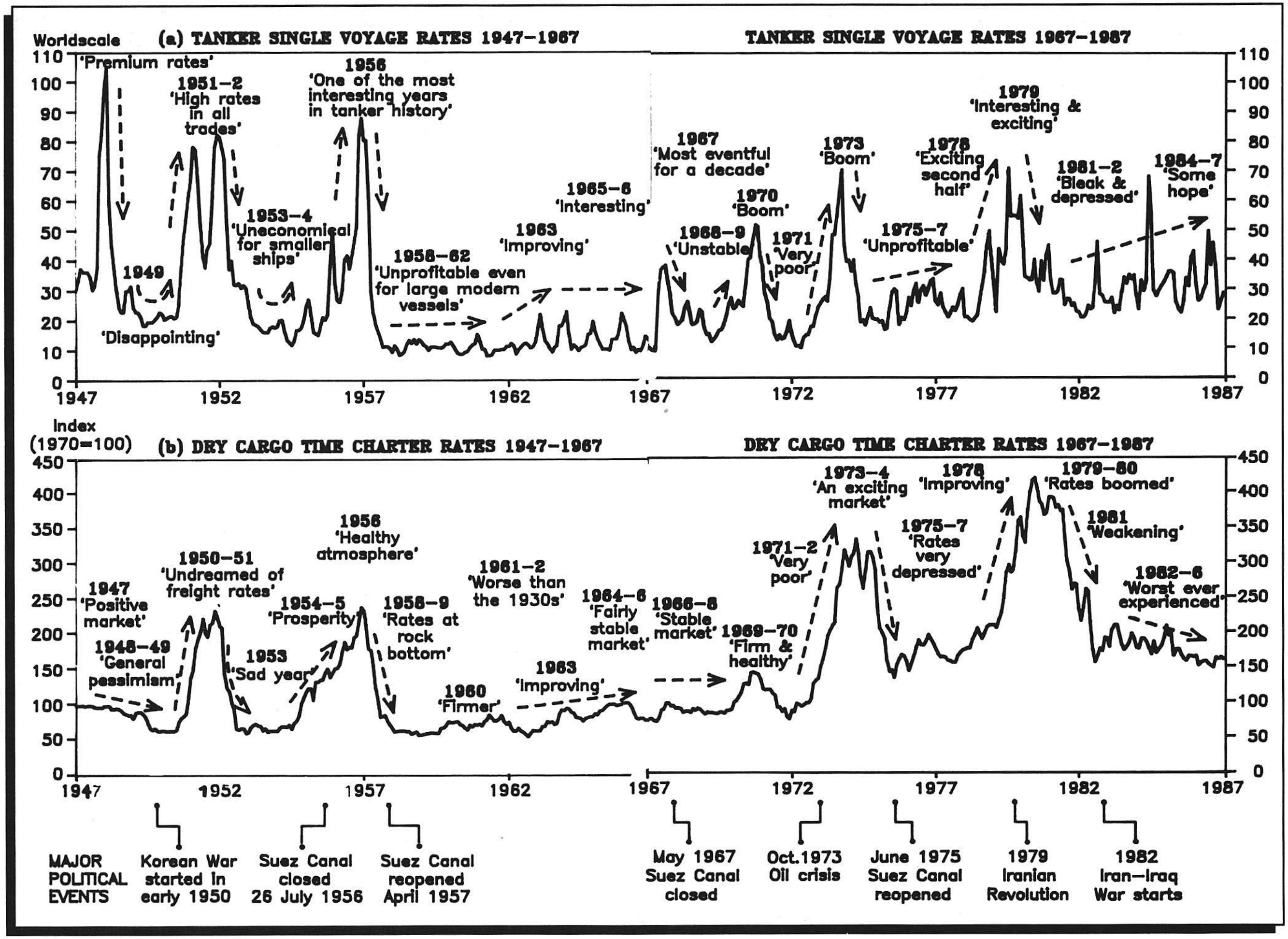


Figure 1: How shipbrokers saw the charter market, 1947-1987

panies have consequently structured themselves in such a way that they can easily adapt to volatile developments.

The turbulence or chaos has in recent times also spread to traditional stable liner shipping. In the past on Ansoff's scale of 2-3, the sector has moved to a turbulence level of 4-5. This has had a profound impact on the structure of the individual firms and the structure of the industry as a whole. The formation of flexible alliances between the container shipping lines is partly an answer to this need to hedge and proactively deal with a higher level of turbulence in the marketplace.
The strong and frequent fluctuations in the freight markets of the mainstream shipping segments, do not really facilitate a long term innovation climate. A lot of shipowners are not in the market to innovate, but rather to survive. The long waves of building up capacity and restructuring of an overcapacity that follows this period, as described in the model of M. Hampton, does not really stimulate owners to innovate, as most of the years, the freight level is insufficient to create any competitive edge in the market. The strategies of cost leadership, market differentiation and focus, the generic strategies proposed by M. Porter in the following sections, are practiced by relatively few owners during these periods.

11.2 Strategies

11.2.1 Innovation and strategy

In the 1950s, when response to environmental discontinuities became important, the concept of strategy entered business vocabulary. In the early days, writes Ansoff, the meaning of the concept was not clear. The military usage of the term defined it as "the science and the art of deploying forces for battle".
At first, managers and academics questioned the usefulness of the new concept, but over the last decades, it has been widely accepted.

Before one important aspect of strategy is discussed, what Ansoff calls *"The Competitive Posture Analysis"*, it is useful to describe the strategic concept in more detail. A strategy has several distinguishing characteristics:

1. The process of strategy formulation results in no immediate action. Rather, it sets the general directions in which the firm's position will grow and develop;
2. Therefore, strategy must next be used to generate strategic projects through a search process. The role of strategy in search is first to focus on areas defined by the strategy, and second to filter out and uncover possibilities that are inconsistent with the strategy;

3. Thus, strategy becomes unnecessary whenever the historical dynamics of an organisation will take it where it wants to go. This is to say, when the search process is already focussed on the preferred areas;
4. Strategy formulation must be based on highly aggregated, incomplete and uncertain information about classes of alternatives;
5. When search uncovers specific alternatives, the more precise, less aggregated information that becomes available, may cast doubts on the wisdom of the original strategy choice. Thus, successful use of strategy requires strategic feedback.
6. Objectives represent the ends that the firm is seeking to attain, while the strategy is the means to these ends. A strategy that is valid under one set of objectives may lose its validity when the objectives of the organisation are changed.
7. Strategy and objectives are interchangeable; both at different points in time and at different levels of organisation. Thus, some attributes of performance (such as market share) can be an objective of the firm at one time and its strategy at another. Further, as objectives and strategy are elaborated throughout an organisation, a typical hierarchical relationship results: elements of strategy at a higher managerial level become objectives at a lower one.

Thus strategy is a somewhat abstract concept. Its formulation produces no immediate productive action in the firm. Above all, it is an expensive process both in terms of money and managerial time.
The formulation of a strategy becomes essential when rapid and discontinuous changes occur in the environment of the firm. This may be caused by saturation of traditional markets, technological discoveries inside or outside the firm, and/or a sudden influx of new competitors. Under these conditions, established organisational traditions and experience no longer suffice for coping with the new opportunities and new threats. Without the benefit of a unifying strategy, the chances are high that different parts of the organisation will develop different, contradictory and ineffective responses.

When confronted with discontinuities, the firm is faced with two very difficult problems:

1. How to choose the right directions for further growth from among many and imperfectly perceived alternatives;
2. How to harness the energies of a large number of people in the new chosen direction.

Answers to these questions are the essence of strategy formulation and implementation. Again all this is done in order to compete and survive in the battlefield, which is called world market.

Analysis of the competitive strategy of the firm starts with the strategic segmentation of its businesses and the formulation of a strategy requires first of all an answer to the question: "*What business is the firm in?*" As firms are made up of many businesses (product-market combinations), it is necessary to define a unit of analysis. Ansoff uses for this purpose the strategic business area (SBA); a unit that is responsible for the strategy formulation of various SBA's is called a strategic business unit (SBU). **Figure 2** shows the relationship between the two definitions.

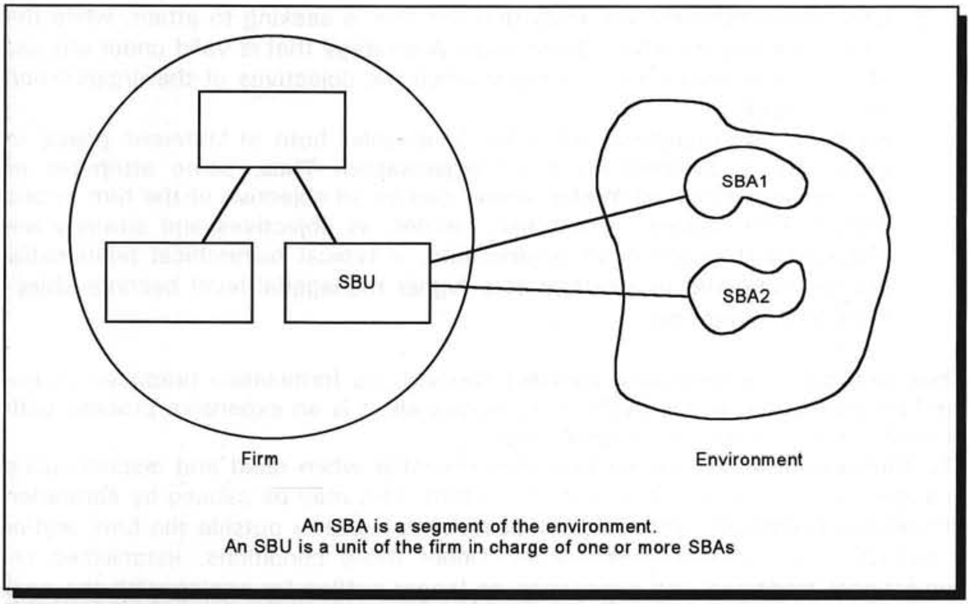


Figure 2: SBA versus SBU

11.2.2 Demand-technology life cycle

In a previous chapter the concept of product life cycle was introduced and discussed. In order to understand the dynamics of change that lay at the foundation of innovation, this concept is further developed by Ansoff, when he includes explicitly demand-technology cycles (**Figure 3**).
The demand life cycle describes a typical evolution of demand from the day as previously unserved societal need begins to be served by products or services. The demand-technology life cycles (labeled T1 and T2 respectively) that determine the demand for products/services based on a particular technology. The lower part of **Figure 3** llustrates that within the demand-technology life cycle, successive product life cycles are based on the technology that originally served demand.

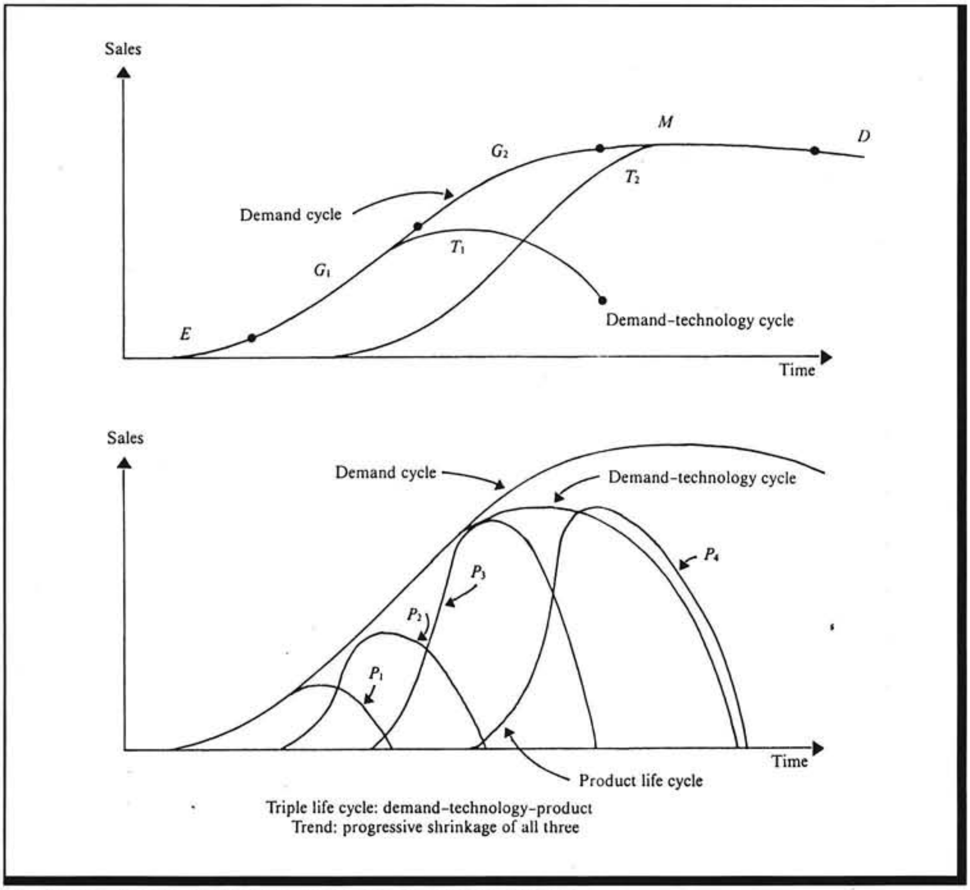


Figure 3: Demand-technology-product life cycles

As this book discusses design innovation in shipping, technology is at the centre of its interest. In the following section, the strategic dimensions of technology, as defined by Ansoff, will be discussed in more detail.

11.2.3 Strategic dimensions of technology

When the concept of strategy was first developed, the focus was on economic and competitive variables. R&D, like production, was treated as a functional area to which strategic decisions could be assigned for 'implementation'. Since the 1950s it has become increasingly evident that, in certain industries, technology was becoming a driving force that could shape the strategic future of an enterprise.

In **Figure 3**, the importance of technological change in the evolution of the demand life cycle was illustrated. This concept is further developed in **Figure 4**, in which the upper graph demonstrates a stable, long-lived technology that remains basically unchanged for the duration of the demand life cycle. When product proliferation occurs during the G2 phase, it is based on product features and design cosmetics rather than on technological advances in product performance.

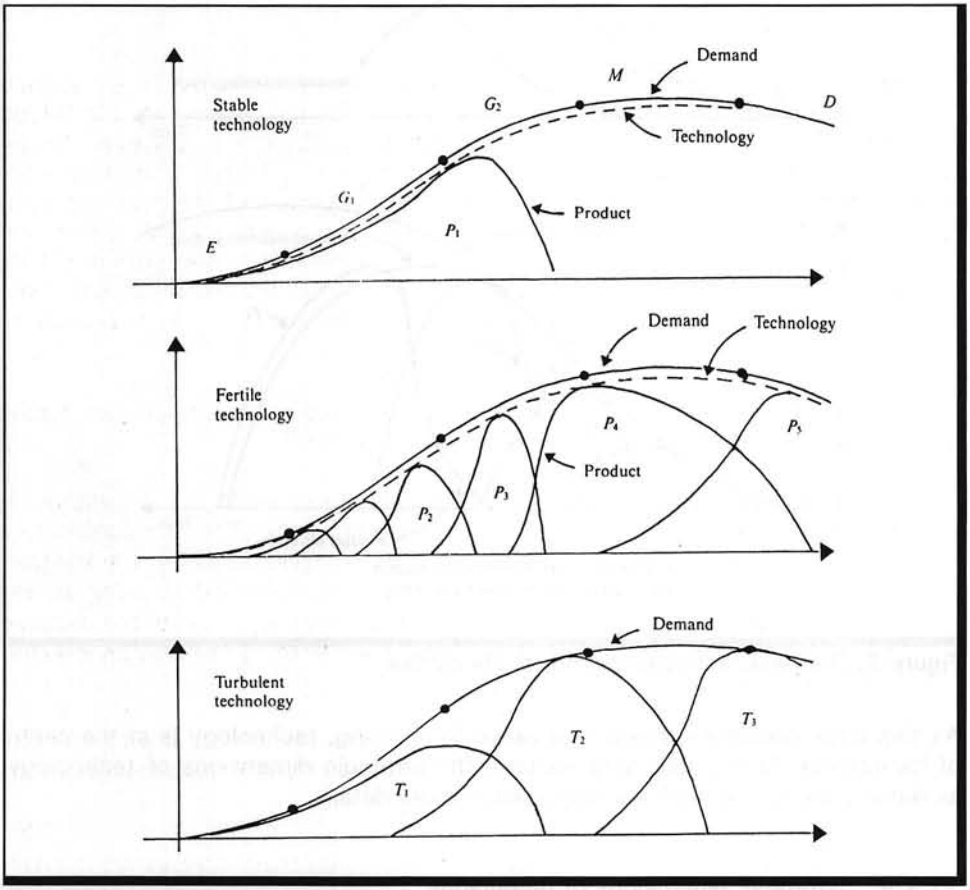


Figure 4: Demand-technology-product life cycles

The middle graph illustrates what is called fertile technologies. The basic technology is long-lived, but products proliferate, offering progressively better performance, and broadening the field of application. In fertile technologies, product development becomes a critical factor in economic success. As product life cycles are short, due to competing products, firms are under constant pressure to innovate.

The third graph demonstrates a turbulent field of technology in which, in addition to product proliferation, one or more basic technology substitutions take place within the life span of the demand life cycle. In other words, this is the case of the S-curve shifts. This figure illustrates clearly the link and difference between demand life cycles, product life cycles and demand-technology life cycles.

11.2.4 Competitive strategy

Igor Ansoff's conceptual models of strategic management create a valuable basis for the understanding of the (technological) change process that is forced upon firms in order to survive in the world markets. There are, however, 'many ways that leads to Rome', as the expression goes. Another important conceptual framework for strategic thinking and management of the firm has been formulated by M. Porter in his book *"Competitive Advantage; Creating and Sustaining Superior Performance"* (1985). As Porter's views have attracted a lot of interest from the business community and are at the basis of his other well-known book on the competitive advantage of nations, his approach to competitive advantage is briefly discussed.

Structural analysis of industries by Porter is based on the five competitive forces that determine industry profitability, as shown in **Figure 5**.

Industry profitability is not a function of what products looks like or whether it embodies high or low technology, but of industry structure. The five competitive forces are: the entry of new competitors, the threat of substitutes, the bargaining power of buyers, the bargaining power of suppliers, and the rivalry among the existing competitors. The five forces determine industry profitability because they influence the prices, costs, and required investment of firms in an industry - the elements of return on investment.

The strength of each of the five competitive forces is a function of industry structure, or the underlying economic and technical characteristics of an industry. Its important elements are shown in **Figure 6**.

Industry structure is relatively stable, but can change over time as an industry evolves. Structural change shifts the overall and relative strength of the competitive forces, and can thus positively or negatively influence industry profitability. The industry trends that are the most important for strategy are those that affect industry structure. **Figure 6** highlights all elements of industry structure that may drive competition in an industry. Every industry is unique and has its own unique structure. The five-forces framework allows a firm to see through the complexity and pinpoint those factors that are critical to competition in its industry, as well as to identify those strategic innovations that would most improve the industry's - and its own - profitability.

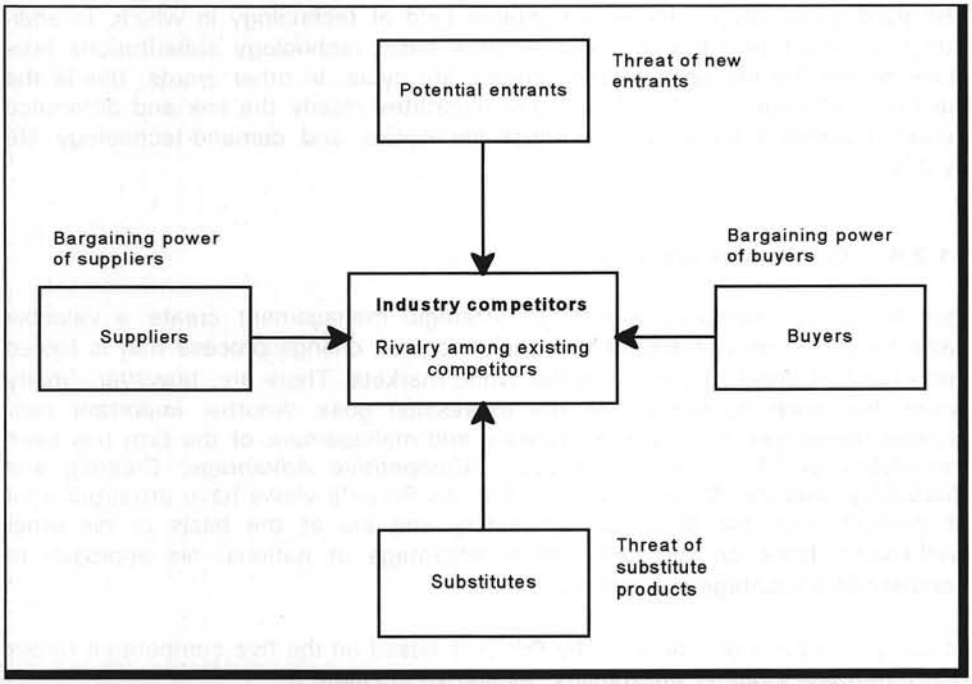


Figure 5: The five competitive forces that determine industry profitability

The fundamental basis for above-average performance in the long run is sustainable competitive advantage. Though a firm can have a myriad of strengths and weaknesses vis-à-vis its competitors, there are two basic types of competitive advantage a firm can posses: low cost or differentiation.
The cost leadership and differentiation strategies seek competitive advantage in a broad range of industry segments, while focus strategies aim at cost advantage or differentiation in a narrow segment. The three generic strategies for achieving above-average performance in an industry: cost leadership, differentiation and focus are shown in **Figure 7**.

Cost leadership means that firm sets out to become the lowcost producer in its industry. The sources of cost advantage are varied and may include the pursuit of economies of scale, proprietary technology, preferential access to raw materials, etc.
In a *differentiation strategy*, a firm seeks to be unique in its industry along some dimensions that are widely valued by buyers. It selects one or more attributes that many buyers in an industry perceive as important, and uniquely positions itself to meet those needs. It is rewarded for its uniqueness with a premium price. The third generic strategy based on focus, rests on the choice of a *narrow segment* or group of segments in the industry. The focus strategy has two variants: cost focus and differentiation focus.

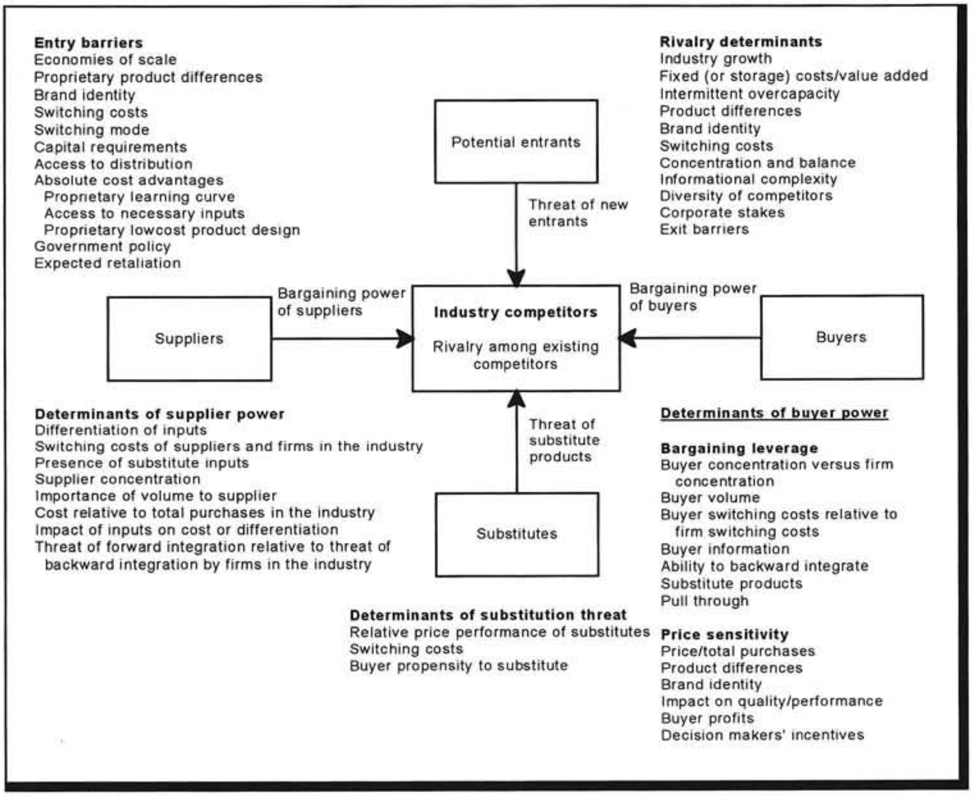


Figure 6: Elements of industry structure

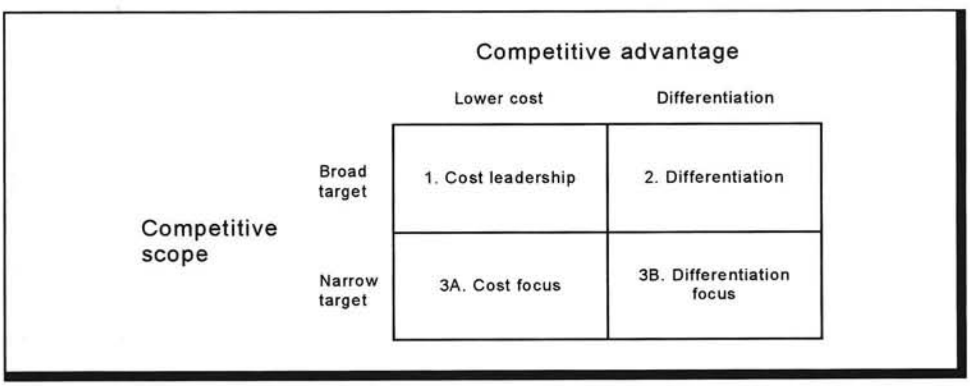


Figure 7: Three generic strategies

These strategies have been illustrated by the case-studies discussed under the the section of Porter's Competitive Advantage of Nations, on the Dutch heavy lift industry and the Norwegian chemical industry (**Chapter 6**).

One of the authors of the latter study, prof. dr. T. Wergeland, has written a strategic analysis of Norwegian Shipping as a whole. Two sections, Strategic Choices, and Technological development in shipping, are reproduced in the next section, as they illustrate very well Porter's concept on strategy for the shipping markets.

11.3 Norwegian shipping: strategic choices and technological development

11.3.1 Strategic choices

<u>**Specialisation and economies of scale**</u>

In order to better understand the kind of strategic options available, it could be instructive to use a classification scheme for shipping that was introduced in a joint study with McKinsey & Co. back in 1989 (McKinsey, 1989) **Figure 8** indicates that there are two important dimensions of shipping; on the one hand, the degree of product differentiation (the degree to which the service has been specialised) and on the other, the degree of economies of scale in the operation and management of fleets.

Economies of scale	Differentiation: Insignificant	Differentiation: Significant
Significant	**Contract shipping** Few suppliers Economies of scale in fleet Fairly homogeneous service Liquid secondhand market Close customer relations	**Industry shipping** Integrated business systems Economies of scale in fleet Specialised services Difficult secondhand market Tailormade customer product
Insignificant	Many suppliers No economies of scale Homogeneous Liquid secondhand market Little direct customers contact **Commodity shipping**	Few suppliers No economies of scale Specialised services Difficult secondhand market Direct customer contract **Specialty shipping**

Figure 8: Strategic choices in international shipping

The two dimensions are not quite unrelated, as differentiation normally offers opportunities of exploiting market power, i.e. enjoying the benefits of being large relative to the market. This gives a crude division of strategic types as follows:

- Commodity shipping (tramp shipping) with a very limited degree of both economies of scale and differentiation;
- Special shipping, where the degree of differentiation is high, but where there is limited scope for exploiting economies of scale;
- Contract shipping, where the degree of differentiation is limited (the services offered are quite homogeneous), but where the size of the operation matters for earnings;
- Industrial shipping, where both the degree of specialisation as well as the degree of economies of scale is very important.

Commodity shipping is typically characterised by almost free competition, and with limited possibilities of earning more than the average in the market. Cost efficiency is the main source of extra income, combined with skillful timing of secondhand operations. Crude oil shipping, most of dry bulk and part of products shipping fall into this category.

Special shipping is quite difficult to find good examples of, simply because differentiation often leads to possibilities of economies of scale. The 'sheep carrier', the heavy lift vessel of Dyvi and the diving vessels of Stolt-Nielsen are possible examples.

The distinction between contract shipping and industrial shipping is not always clear. The main distinction lies in how easily vessels can be sold in the market. Chemical shipping is a typical example of contract shipping as the vessels are fairly standard and can be bought individually in the market. Liner operations or cruise vessels on the other hand are less easy to sell individualy - normally one will have to buy or sell the entire operation.

The strategic map of Norwegian shipping

In a recent study of the competitiveness of Norwegian shipping this classification scheme was used to get an overview picture of the various sectors where Norwegian shipping is active. **Figure 9** shows the way we chose to classify the segments.

The size of each segment indicates nothing about their importance, but rather that within the sector you can find examples of various market types. A good example is liner shipping, where in some segments, as the most competitive container routes, one approaches free competition conditions, while in others, e.g. the Ro-Ro segment, a lot more specialised and tailor made operations are found.

The dry bulk segment could have been made equally large as liner shipping, as one in the most specialised trades will find operations that must be classified as industrial shipping. The idea is not to present a precise picture, however, but

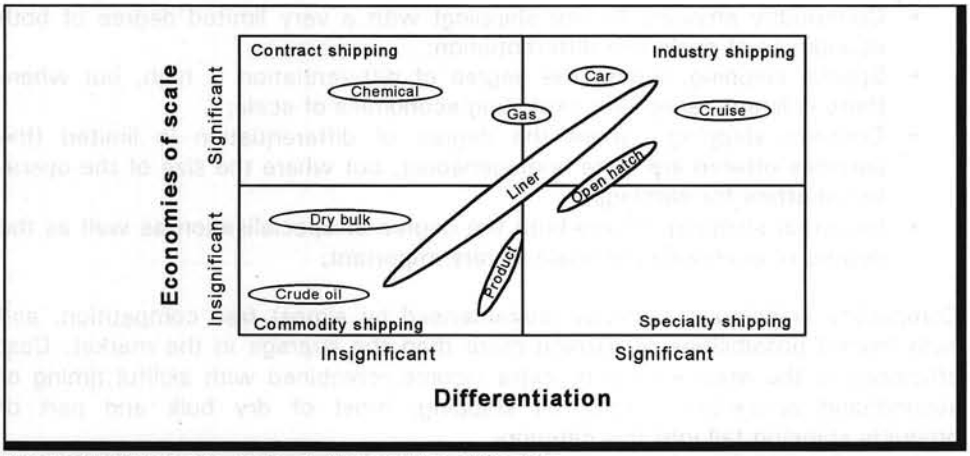


Figure 9: Strategic map of Norwegian shipping

rather to indicate the diversity of Norwegian shipping and the tendency of operations to strive to get as far to the right and the top of the figure as possible. Specialisation and market power put high demands on the shipping organisation running the operation. Customer relations play a dominant role, and long-term visions and strategies are necessary to meet the challenges of constantly changing markets and the fact that the more specialised one gets, the less financial flexibility one has.

Impressive market shares in special segments

In most of the segments in **Figure 9**, Norwegian shipping has managed to obtain impressive market shares. One example is chemicals (**Figure 10**), where the companies Odfjell-Westfal Larsen and JO Tankers have more than 50% of the stainless steel segment of chemical tanker (stensj , 1992).

Similarly, Bergesen and the Myhre-Havtor pool control almost 60% of the medium and large gas tanker segment as indicated in **Figure 11** (Svendson, 1993)

Looking at the smaller segment of the same market, Norwegian Gas Carriers (NGC) together with the Igloo Pool control 60% of the segment between 8,000 and 12,000 cbm (**Figure 12**).

Also in the extremely Japan-dominated car carrier segment, Norwegian interests have managed to survive with a market share of more than 10% (**Figure 13**).

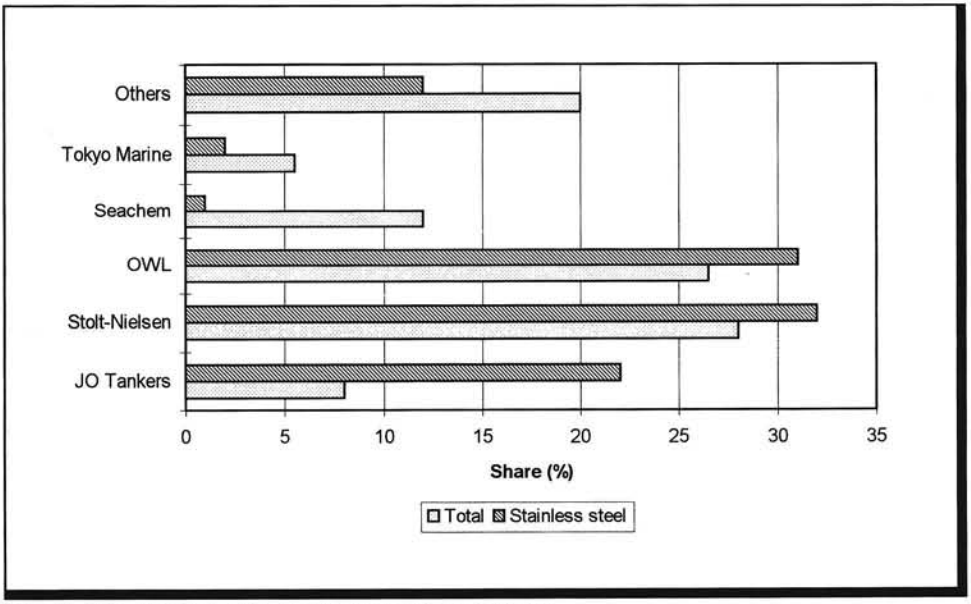


Figure 10: Market shares of chemicals tankers

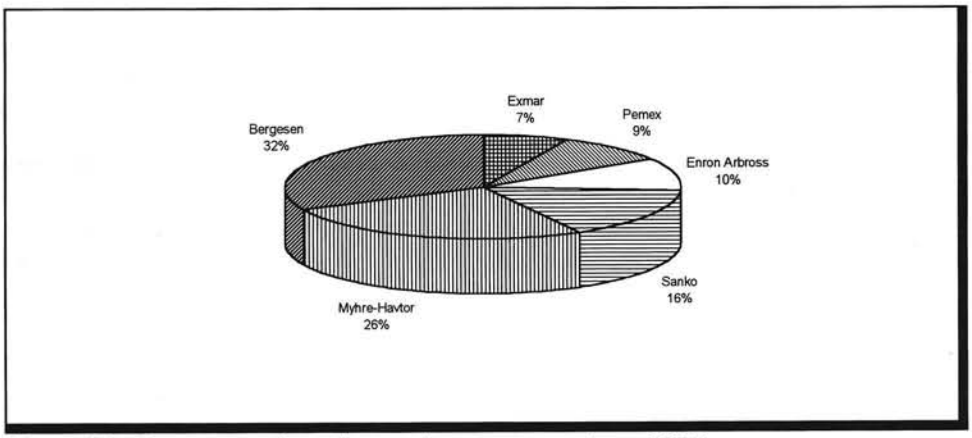


Figure 11: Operators of medium to large gas carriers, 1991

The dynamics of segmentation

The dynamics of strategic types could be illustrated as in **Figure 14**. The point of the figure is to indicate that no market situation is static and given. Over time the conditions of competition change, new market structures form, and the companies must constantly be able to change in step with changes in competition.

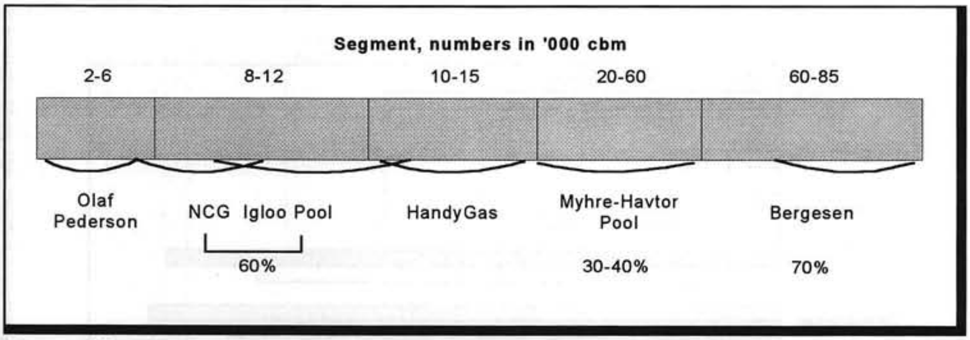


Figure 12: Norwegian pools in the gas tanker business, 1991

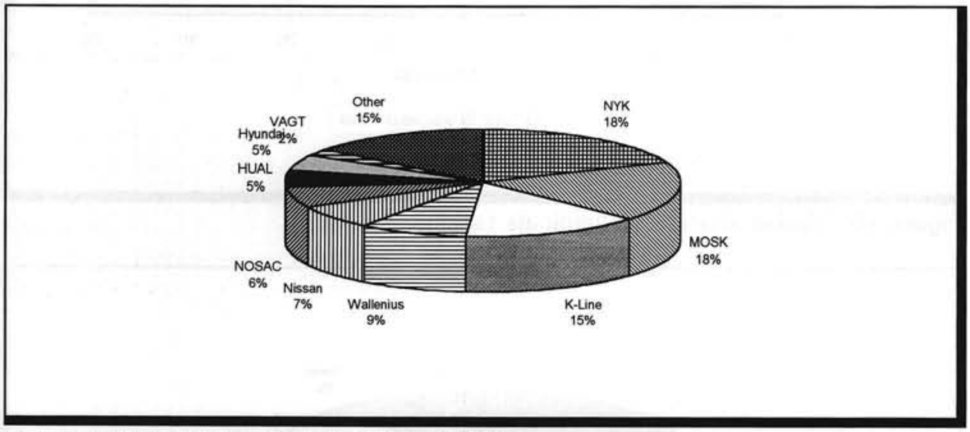


Figure 13: Operators of car carriers, 1991

The normal story is that an innovation occurs (either planned or by chance) which leads to specialisation. Then there are, broadly speaking, three possibilities:

- The concept may be quickly copied by others, which normally leads to overcontracting;
- The concept may get standardised, but the operation may require a certain minimum size to be efficient. This will normally lead to a contract shipping situation;
- The concept remains highly specialised and the operator may enjoy the benefits of market power in a niche operation. This leads to an industrial shipping activity.

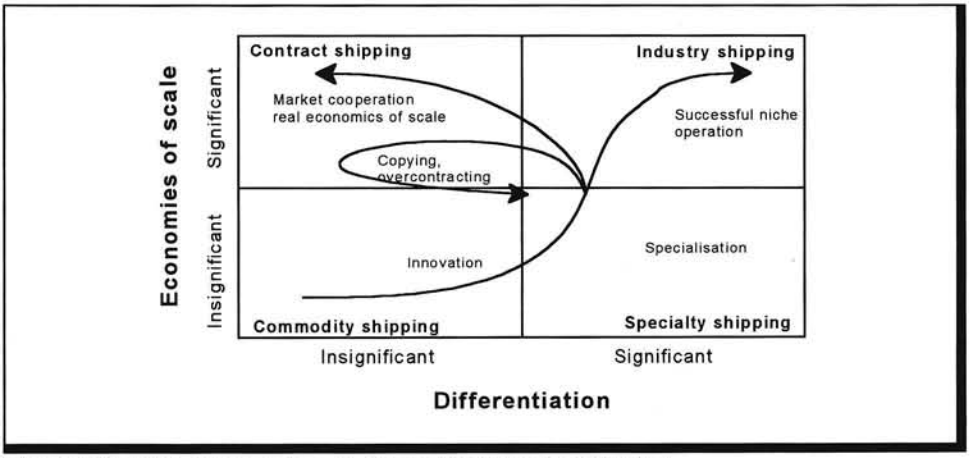


Figure 14: The dynammics of strategic types in shipping

A main point here is that innovations are hard to protect in an environment where technological diffusion is fast and highly international. One needs to constantly adjust the commercial framework to the technical solutions and emphasise customer relations to build commercial barriers to competition where technological protection is difficult. This is often neglected or even forgotten in shipping, as one tends to believe that one's invention or technical solution is so unique that it will sell on its own merit.

11.3.2 Technological development in shipping

Innovations in shipping are normally always connected to technological developments of one sort or the other. Looking back at history, the story of technological development shows that most innovations in concepts are fairly new - almost all the current shipping specialities have been developed over the last 30 years.

Brief history of shipping technologies

The few major events that have changed the face of international shipping substantially, could be said to be:

- 1800 - the steam engine and the transition from sail to steam;
- 1830s - the iron hull;
- 1880s - the steel hull;
- 1920s - the diesel engine;
- 1970s - the turbine engine.

Most of the development toward special shipping shipping types and sizes have occurred in between the diesel engine and the turbine engine. There are obvious incentives that have spurred technological innovation. The transition from sail to steam increased the reliability of shipping and the speed of transport dramatically and led to a complete shift in transport technology. From then on, the major types of innovations have been to exploit the economies of scale in the vessel itself. For a long period of time, the real price of oil was constantly reduced. Consequently, the cost of increasing vessel size in terms of increased fuel consumption became negligible. By increasing the size more than the crew, unit prices of transport were reduced substantially. **Figure 15** shows the development of tanker vessels sizes. All the way up to 1979, tankers have become larger and larger, with the largest tanker vessel ever built being 564,000 dwt. It took about 20 years for the tanker to go from 10,000 to 20,000 dwt (1902-1921), another 30 years to go from 20,000 to around 40,000 dwt. (1920-1953), but from then on the size doubled every 5-8 years from 1953 to 1979, making the 1979 vessel more than 12 times the size of the 1953 vessel.

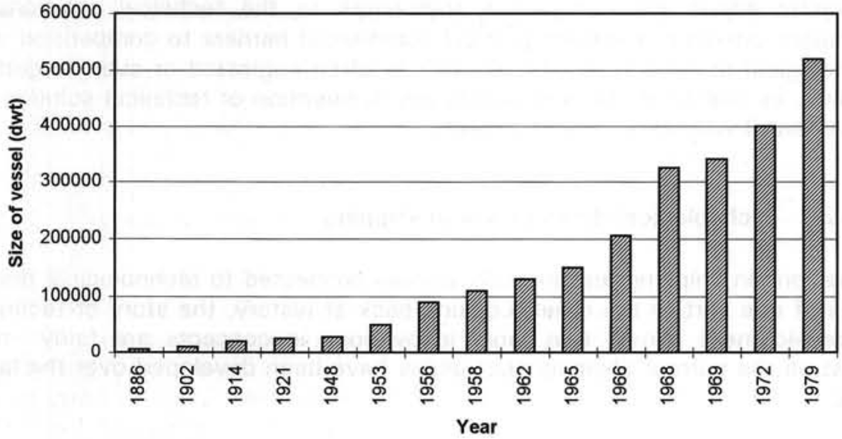


Figure 15: Size of largest tanker at various times in history

To see the effect of the increases in vessel sizes on the employment of seamen, **Figure 16** could be instructive. Here the employment of both Norwegian and foreign crew is measured against the Norwegian fleet development.

The total number of crew decreased rapidly from the mid sixties although the fleet continued to increase dramatically. Looking at the average sizes of vessels as in **Figure 17**, also clearly indicated that particularly in the decade 1965-1975

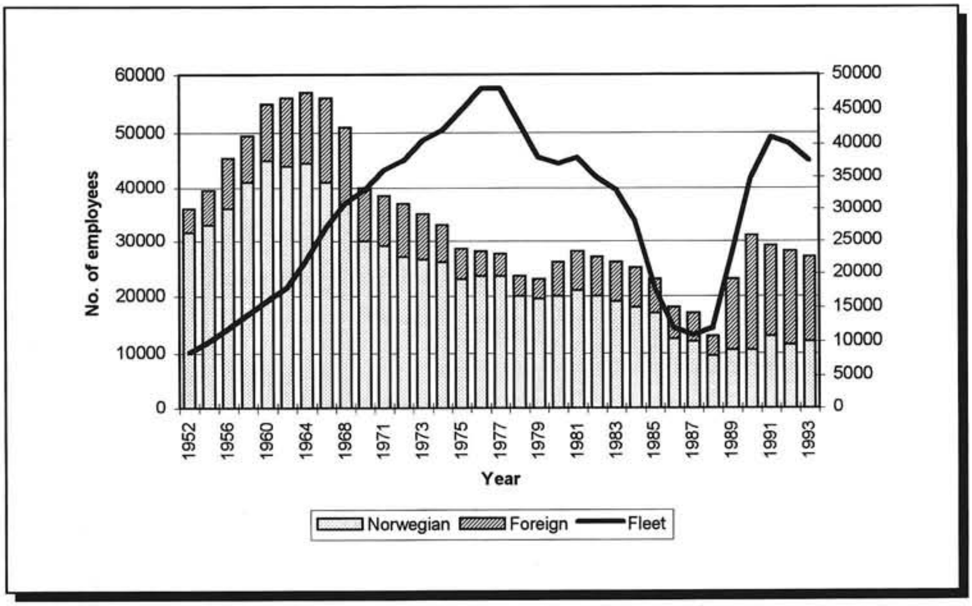


Figure 16: Effects of increase in vessel sizes on crew employement

the average size of vessels increased particularly in the Greek, U.K. and Norwegian fleets. After the oil crises in 1973-1974, however, this motivation of technological development backfired.

To show this, **Figure 18** displays the cost structure of carrying crude oil between the Middle East and Northern Europe.

From 1967 to 1973 the fuel cost component had been reduced from 19% to 11% of the total costs, while capital costs counted as much as 54% in 1973. In 1980 the major cost component was fuel (45%). Currently the capital cost and fuel cost elements account for about 70% of the total costs of carrying crude oil, but due to somewhat lower fuel prices combined with more fuel efficient propulsion systems, the fuel cost component has been reduced to 19%. The increased importance of fuel costs led to a rapid technological development in propulsion systems and engines, a development that reversed the tendency to build ever larger vessels, simply because very large vessels require much fuel.
Looking at the current situation for larger bulk vessels, it is fair to say that very little has happened over the last 20 years except for better fuel economy. This is currently a major problem.

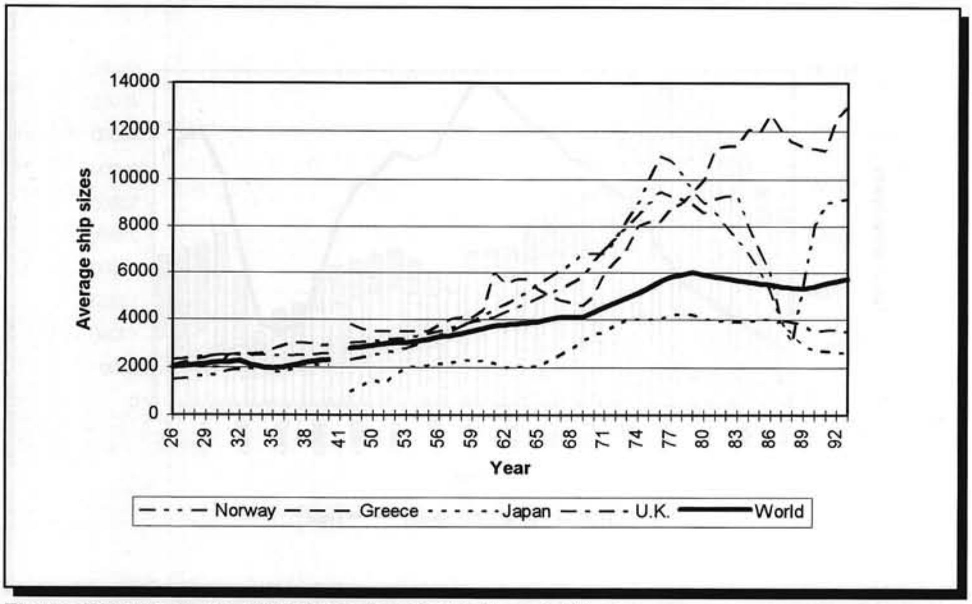


Figure 17: Average ship sizes in selected world fleets

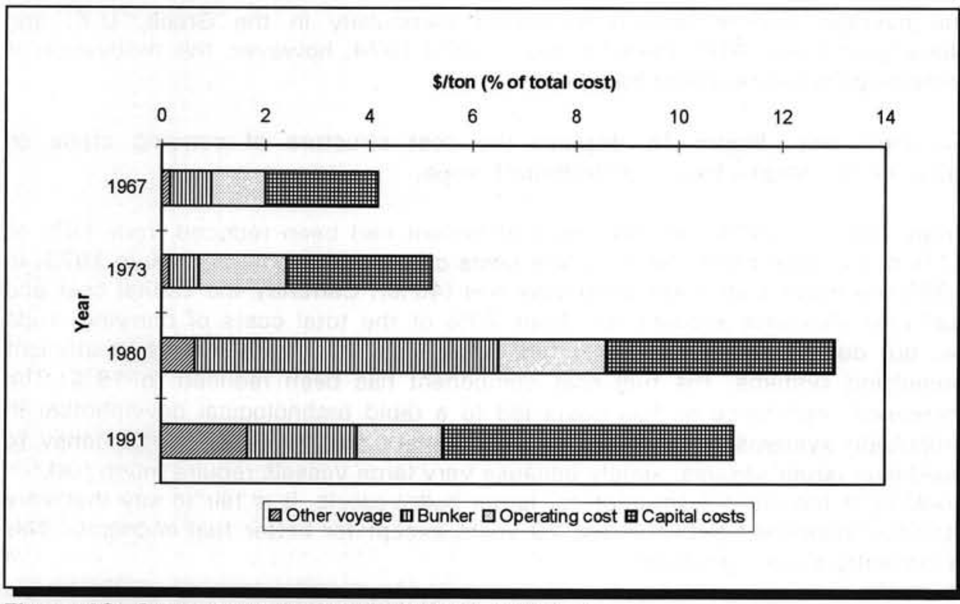


Figure 18: Cost components of crude oil shipping

The Norwegian role in the technological development

Norwegian shipping has always played an active role in developing new vessel types and new transport concepts and is thus a shipping nation very much associated with the contracting of new vessels. Without going into detail, some examples of innovative behaviour of Norwegian maritime operators are given for some shipping segments. Details are to be found in the sources stated:

- *Car carriers (Bruåsdal, 1993)*
  1964: Dyvi Anglia (450 cars); the first pure car carrier;
  1968: Dyvi Oceanic (2500 cars); PCC for intra-regional trades;
  Consultant: Arnesen, Christensen & Co.
  Builder: Torsvik Verksteder (Aker)

- *Gas Carriers (Svendsen, 1993)*
  1959: First vessel with combination of cooling/pressure
  Operator: Ivind Lorentzen
  Consultant: DNV
  Builder: Fredrikstad Mekaniske Verksted
  1965: Fully cooled LPG carrier
  Consultant Kværner
  Builder: Moss Verft
  1966 Ethylene carrier
  Operator: Einer Bakkevig

- *Open hatch bulk carrier (Stokseth, 1992)*
  1963: Rondeggen (first open hatch vessel)
  Operator: Chr. Ostberg (for Crown Zellerbach)
  Builder: Kaldnes Mekaniske Verksted
  Later: Munck gantry cranes
  Star shipping/gearbulk

Other innovative examples are to be found in cruise shipping, where Kloster pioneered modern cruises in the Caribbean (Martinussen, 1992) the heavy lift vessel, designed by Jan Erik Devy in cooperation with R.S. Platou, built at Kaldnes Mekaniske Verksteder (Tvedt, 1992); the super flex product carrier developed by Libæk & Partners (Tvedt, 1992) or the chemical tankers, where several Norwegian shipyards have been active presenting new designs, notably Ankerlokken-Flor (Kværner). The various Kværner owned ship yards today hold more than 70% of the world order book of larger chemical tankers (Ostensjo, 1992).

Concepts that look promising and evolutionary often attract a lot of interests in the Norwegian shipping community. Looking at the contracting made for combined vessels in the early sixties, as indicated in **Figure 19**, clearly shows that Norwegian investors have been leading the way in introducing new concepts also in more standard bulk shipping.

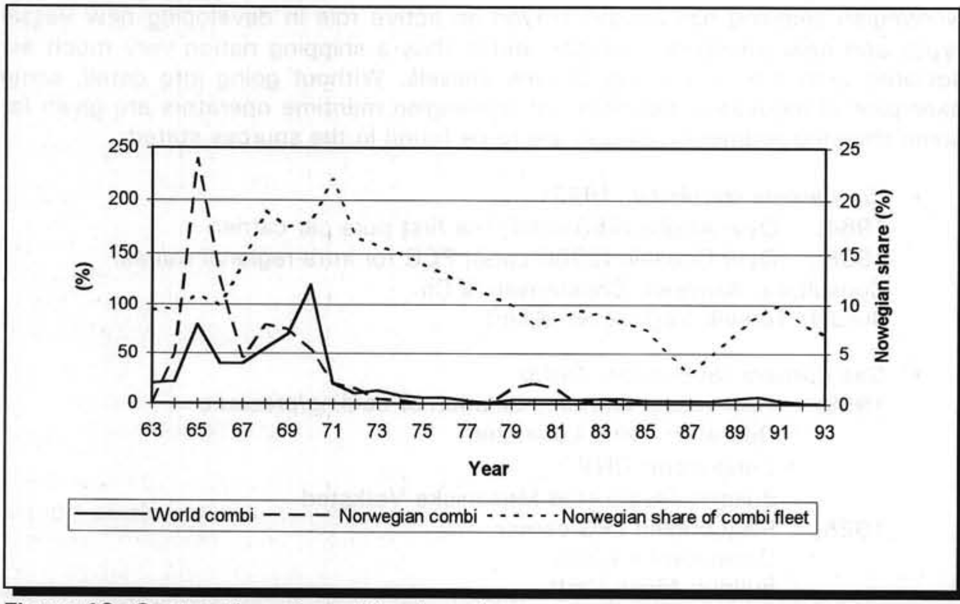


Figure 19: Contracting of combined carriers

11.4 Shipping company strategy: the container sector

This chapter on innovations in firms will be concluded with a look at the strategy of a shipping company, as published in its Annual Report. This document provides the layman with a good insight in the strategy of the firm and the implicit competitive advantages of the firm. The Amsterdam-listed company Royal Nedlloyd Group will be briefly discussed here.

Nedlloyd 1994

Nedlloyd's Annual Report 1994 defines the strategy of Nedlloyd Lines (the container shipping division) as follows. In the logistic services market many customers are looking for a good base level product. A growing number, however, are looking for a more developed logistic support capability. Nedlloyd aims to be able to serve either type of customer based on cost leadership and an ability to combine and coordinate all logistic knowledge and capacity available within the Company. Basic principle is to achieve an adequate return on capital employed.

The Nedlloyd's strategy focuses on supplying a solid base level product via a global network developed in collaboration with strategic partners. A major step forward in this strategy was the alliance announced in 1994 linking Nedlloyd Lines, American President Lines, the Japanese Mitsui O.S.K. Lines, and the Hong Kong-based Oriental Overseas Container Line. Cost leadership is the central objective of this cooperation.

Through this alliance, the frequency of the Europe/Far East services, in which Malaysian International Shipping Corporation participates as well, has been increased from one to two sailings a week as from 1 March 1995. In early 1996 a third weekly sailing will be added. This service accounts for well over forty percent of the total volume transported by Nedlloyd lines.

The Global Alliance is not limited to sea transport alone but will extend to the landside activity as well, where sixty to seventy percent of the shipping companies' costs are incurred. The joint operations lead to *economies of scale, providing better service to the clients as well as improvement in utilisation and productivity*.

S-curve shift general cargo - container ships

Nedlloyd, at that time operating under an other name, was one of the liner companies in Europe that had to be transformed at the end of the 1960s from a general cargo liner company into a container shipping line. The shift was not based on a fashionable 'follow the crowd' basis, since at that time, nobody was sure whether the container-innovation would become the dominant trend. It was based on rational analysis, which is demonstrated here in three graphs, **Figure 20** to **Figure 25**, made by ir. E. Vossnack, chief naval architect of Nedlloyd, during this turbulent period. Conventional liner companies were facing three major problems:

- The round-trip time of the conventional ships could not be reduced, as the largest part of the trip the ships were waiting for a berth in port, and actually being loaded and discharged;
- In spite of the continuous improvements of the conventional general cargo liner, such as heavy cranes, larger hatches, flush decks, stevedoring equipment and pallets, the port time remained too long, which made it impossible to increase the size of the vessel above 15,000 dwt.; this put a cap on the possibility to create economies of scale in the design;
- The labour cost of the seamen, the large crews on board conventional vessels, and the increasing stevedoring cost in port, resulted in a steep increase in the total transport cost per cubic feet of capacity.

Figure 20 illustrates the cost development of a conventional liner service based on a 12 ships, 6 months round-trip time, and two week sailing frequency. The annual transport capacity by this service is 37 million cubic feet (cuft). In 1958, the transport cost in Dutch guilders per cuft were approximately NLG 1.60; by

1968 this had increased to NLG 2.00 and the increase in 1974 was to a staggering NLG 3.30 and by 1979, this cost had increased to NLG 4.30 per cuft., a 260 percent increase from 1958 to 1979, in spite of all the creative effort that resulted in a multitude of improvement innovations. In essence, however, the general cargo ship's concept had not changed from as from 1900, as **Figure 21** and **Figure 22** clearly demonstrate.

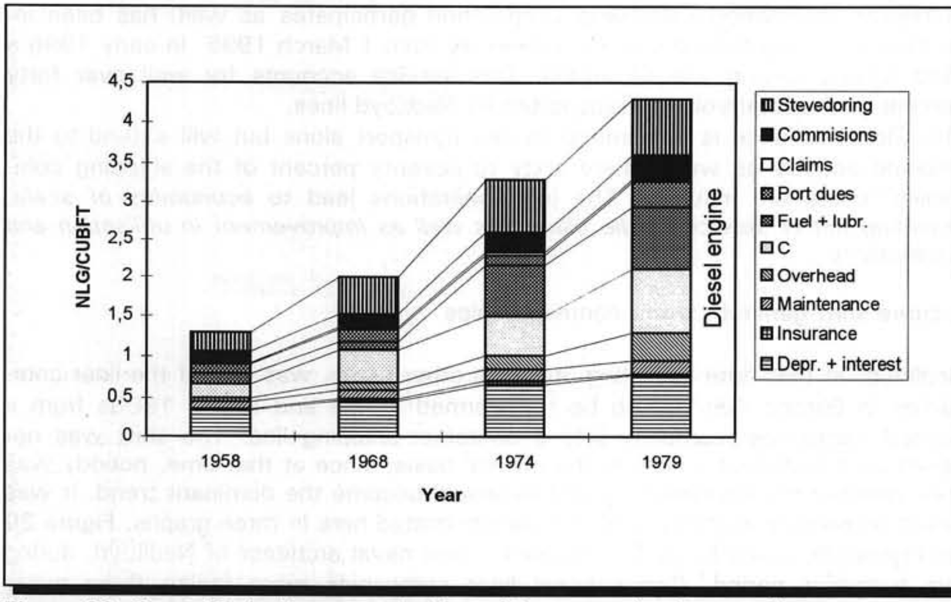


Figure 20: Costs/Cuft. Europe - Far East, 12 conventional cargo liners

Early 1970 Nedlloyd decided to fundamentally innovate the container ship, together with another European shipping line. A virtual quantum leap in design was achieved in the span of a few years, towards a 2600 TEU ship, the well-known *Nedlloyd Dejima* and *Nedlloyd Delft*.

The two cellular vessels were able to substitute easily the 12 conventional cargoliners; the carrying capacity increased even from 37 to 48 million cuft per year. The cost per cuft decreased dramatically from NLG 3.30 in 1974 for the conventional service to NLG 2.30 for the two ship container service. This is illustrated in **Figure 23**.

A comparison of the detailed cost structure of transport cost in the two cases, reveals that the capital cost, maintenance cost, fuel cost, port cost, and stevedoring cost decreased. The latter cost item can not be compared realistically in both figures, as the conventional service is based on stevedoring cost from shed to shed, while the container stevedoring cost, include the door-to-door delivery and pickup cost. A correction for this difference, would reveal a dramatic reduction in stevedoring cost per cuft for the container service.

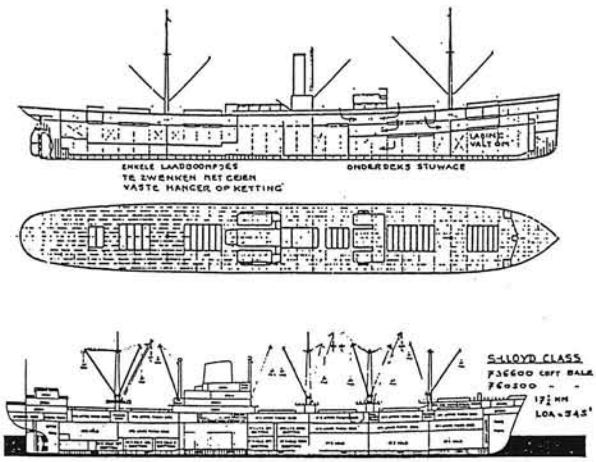


Figure 21: General cargo ships from the years 1900 and 1958

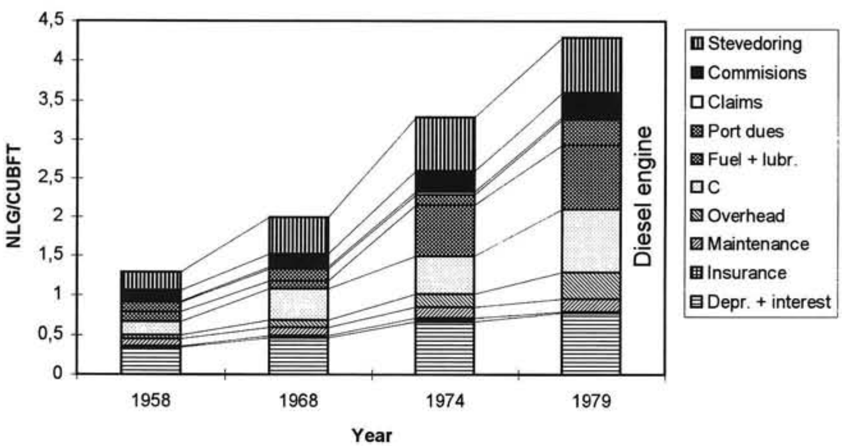


Figure 23: Costs/Cuft Europe - Far East, 2 cellular container ships

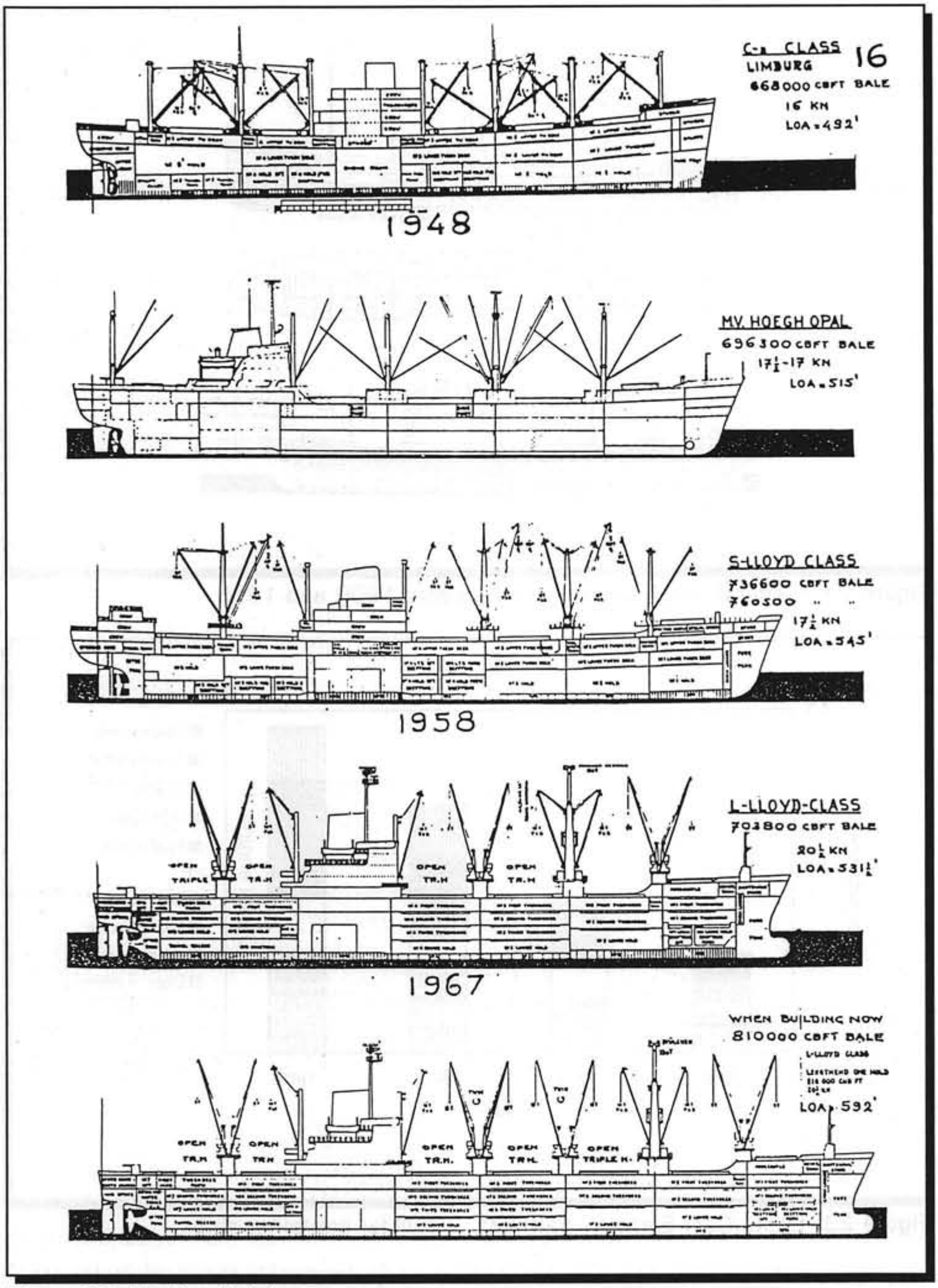


Figure 22: Nedlloyd ships

One of the major reasons for a lower cost figure can be traced to a dramatic reduction in round-trip time of the container service in comparison with the conventional service. **Figure 24** shows the turnaround time of a conventional service of 180 days, of which only 75 days or 42 percent was spent on sailing at sea, the remainder, 58 percent, was spent either waiting or alongside the quay for cargo handling.

Figure 25 shows a different container service with a round-trip time of 75 days, of which 54 days or 72 percent were spent at sea and the remainder, 28 percent, in port. The difference is explained by the elimination of waiting times and the phenomenal increase in stevedoring productivity through the use of unitised cargo. The effective productivity in tonnes/hour increased from 30-60 tonnes for the conventional service, to 223-446 tonnes for the container service.

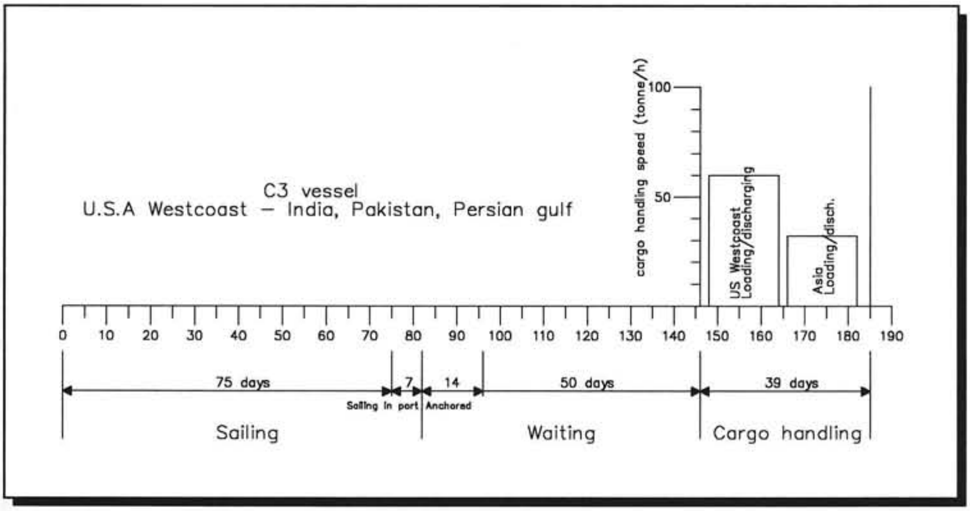


Figure 24: Reduction of roundtrip, speedup cargo handling

Yet another aspect became important in container shipping: the possibility to increase the size of the vessel, without prolonging the turnaround time in port dramatically. This lead to important economies of scale in container shipping. The relationship between container ship size and economy is further discussed in the following section.

11.5 Economy of scale of container ships

The increase in ship size is driven by the effect of diminishing capital cost, operating cost and voyage cost per TEU. This so-called economy of scale effect can be witnessed in the charter market of container ships. In the book *"Analysis*

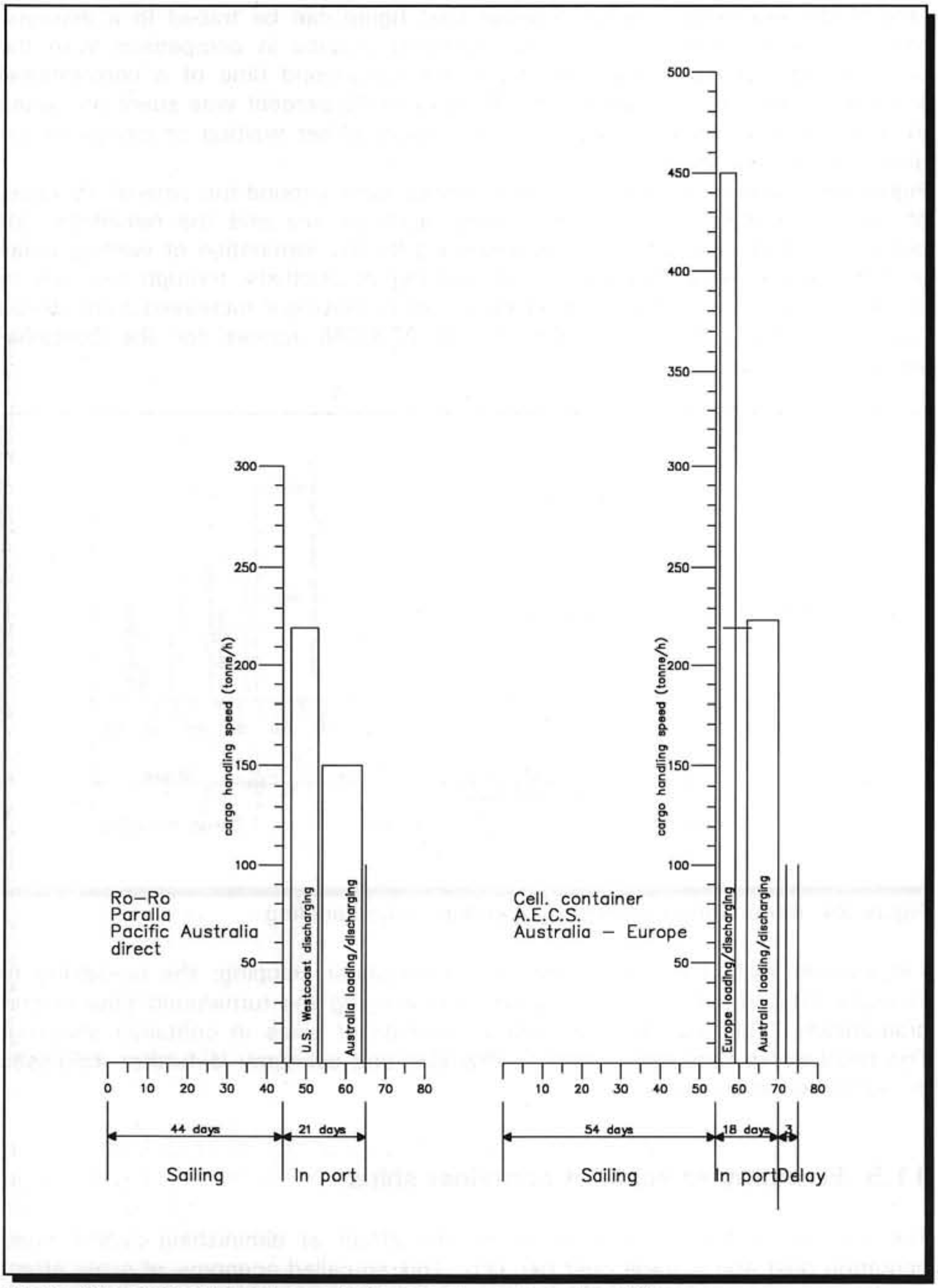


Figure 25: Reduction of roundtrip, speed up cargo handling

of the Container Ship Charter Market 1983-1992", the relation between container ship size (TEU) and charter rate is studied. Other important variables are the speed of the vessel and the corresponding fuel consumption; a high service speed is valued by the charter market by a premium, in particular in the smaller ships segments up to 1000 TEU.

Figure 26 shows these relationships graphically. The charter rate should compensate the owner for the capital cost of the ship and the operating cost; voyage cost are for account of the charterer. The graph shows that a small container ship of say 200 TEU has a capital plus operating cost (charter rate per TEU) that is two times that of a vessel of say 1000 TEU.

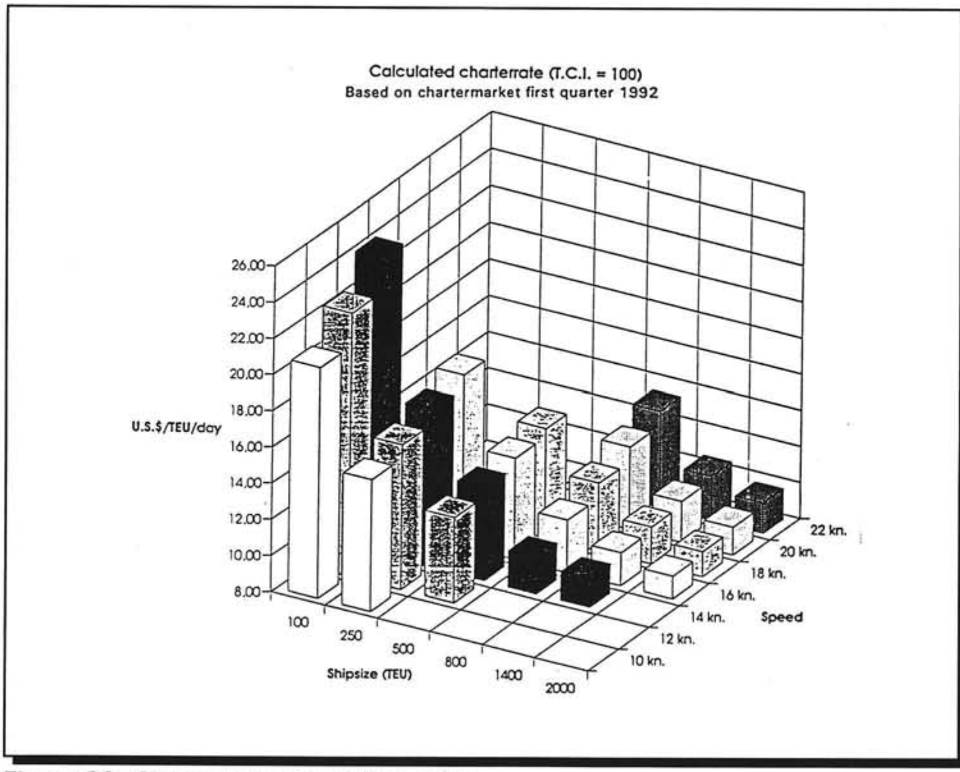


Figure 26: Charter rates container ships

The *capital cost* of a fully cellular container ship, decline substantially with an increase in size, although the marginal reduction levels off rapidly beyond a ship size of 4000 TEU. When a ship increases in size, it increases in volume, which is a function to the third power (cubic metres). The outer steel hull (surface), increases with the second power (square metres). The cost of a ship is related to the steel weight, which increases less than volume. The relationship of capital cost (US$/TEU/day) and size is shown in **Figure 27**.

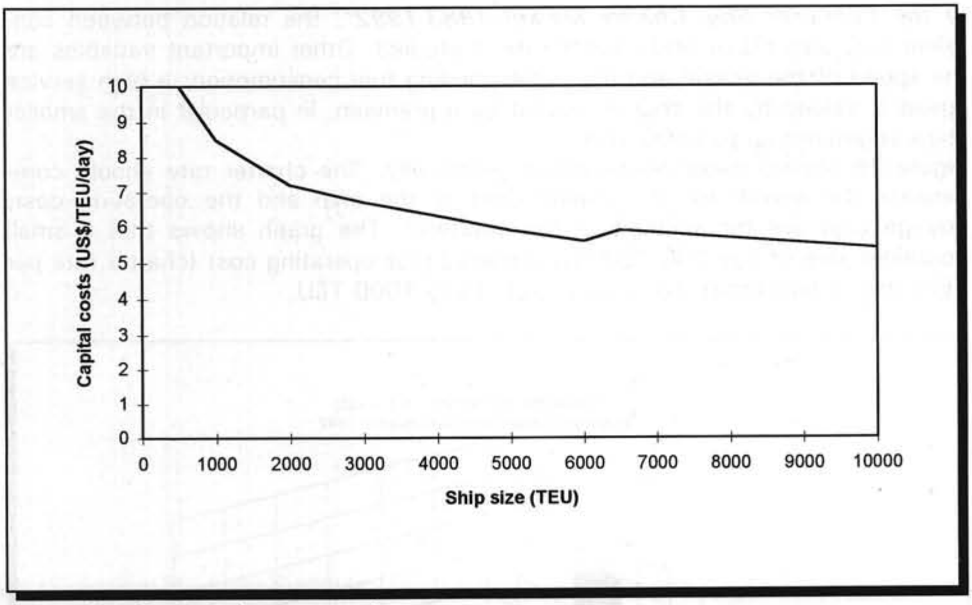


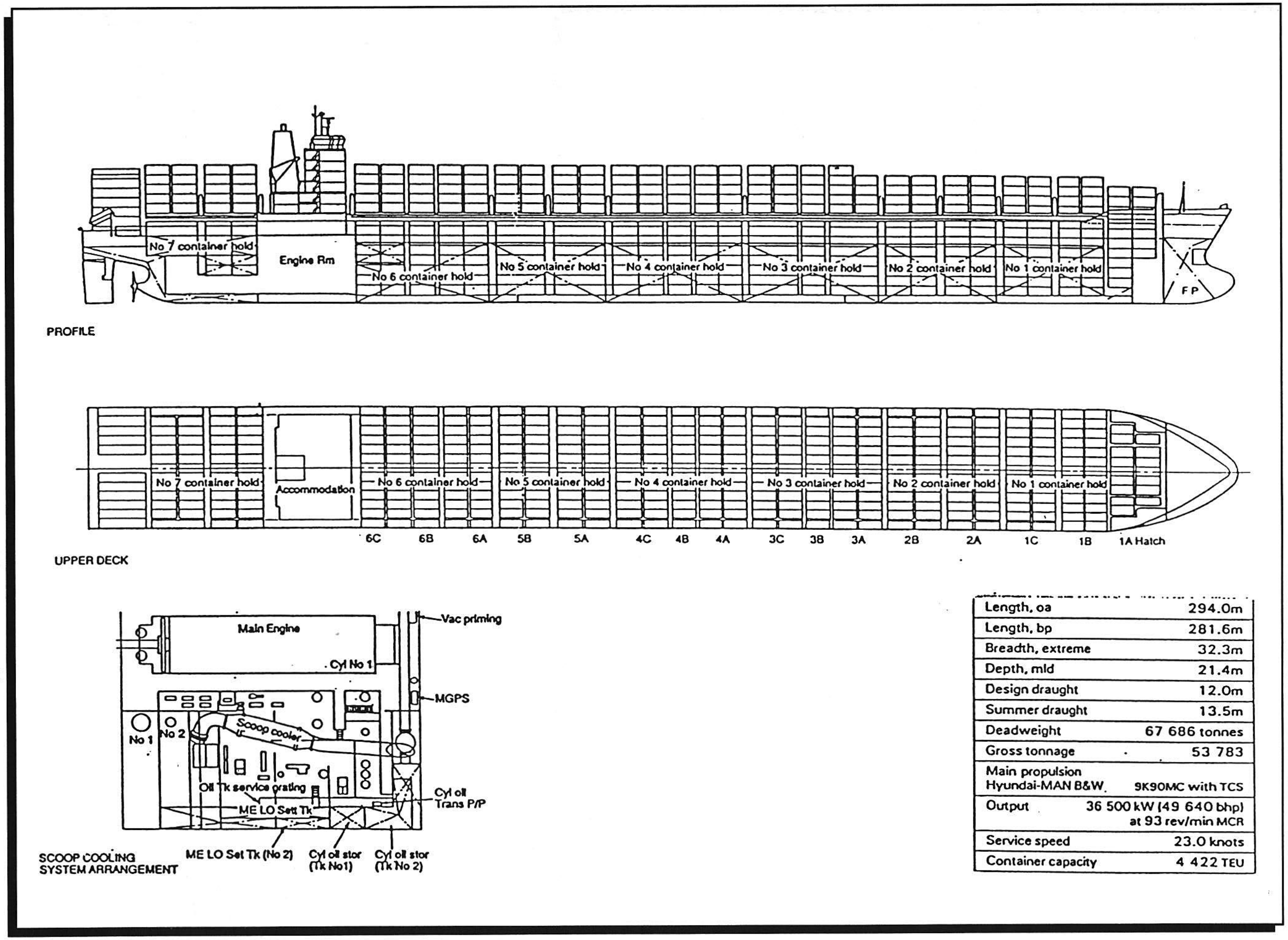
Figure 27: Capital charges - unit costs

The operating cost per TEU depend to a large extent on the crew cost; these decline very fast in the smaller segment of the market, but again the economy of scale is reduced for larger vessels. The voyage cost will go down with an increase in size, as these are related mostly to fuel cost (but port cost as well). The fuel consumption depends on the installed power and this in turn is determined by the speed and the resistance in water. The resistance depends on the wetted surface of the ship's hull and wave impact. When a ship increases in size (volume), the wetted surface increases less, which explains the fuel economy.

The current size of container ships approaches the 5000 TEU mark. An example of such a large vessel is Hapag Lloyd's Hanover Express (**Figure 28**). Recently Hapag stated that the company was looking into even larger ship sizes. The following quote from Lloyd's List (9.5.95) illustrates clearly the economy of scale.

"*By switching from 2500 TEU to 4400 TEU, costs could be cut by about 50%. Between the 6000 TEU vessel and the 4400 TEU type, cost saving comes down to 10 to 15%, due to high construction costs. But the cost saving is still attractive.... The introduction of 6000 TEU or even 8000 TEU vessels would lead to a reduction in sailings, and shipping lines would have to intensify cooperation. The increase in ship size also triggered an increase in container gantry capacity.*"

An example of the next generation of 8000 TEU ships and the consequent change in handling facilities in port is offered by the German yard HDW (in LL-magazine May 1995), see **Figure 29** and **Figure 30**.



Length, oa	294.0m
Length, bp	281.6m
Breadth, extreme	32.3m
Depth, mld	21.4m
Design draught	12.0m
Summer draught	13.5m
Deadweight	67 686 tonnes
Gross tonnage	53 783
Main propulsion Hyundai-MAN B&W	9K90MC with TCS
Output	36 500 kW (49 640 bhp) at 93 rev/min MCR
Service speed	23.0 knots
Container capacity	4 422 TEU

Figure 28: General arrangement container ship *Hannover Express*

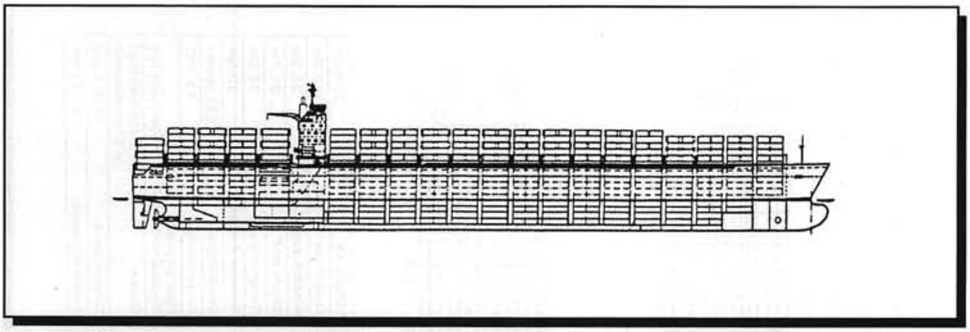


Figure 29: The next step in container ship design

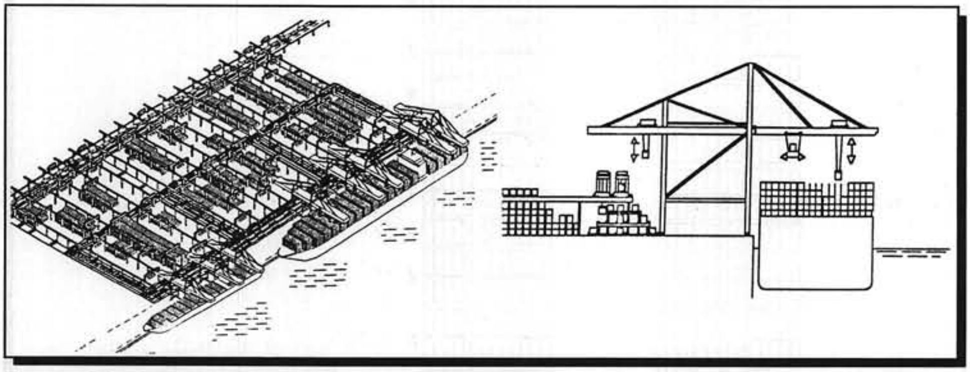


Figure 30: Container terminal

Dis-economy of scale in container shipping company size.

In spite of the phenomenal increase in investment in new, larger ships, the major container lines did not manage for many years to create a decent return on investment. In a paper for a container conference in 1992, I have demonstrated this as well as provided a diagnosis for this seemingly bizarre paradox: cost leadership through economy of scale in ships is counterbalanced by dis-economy of scale in shipping company's size.

Figure 31 shows the return on assets of - at that time - 10 major shipping lines over the period 1980-1989. During this ten year period, the investment increased to US$15 billion, while the average return on assets hovered around one percent, not taking into account the inflation during this period. **Figure 32** shows the counteracting forces on the return on investment of the typical container shipping line.

Small container lines have small overheads and simple administrative and operational systems. They usually operate in a regional niche, which does not

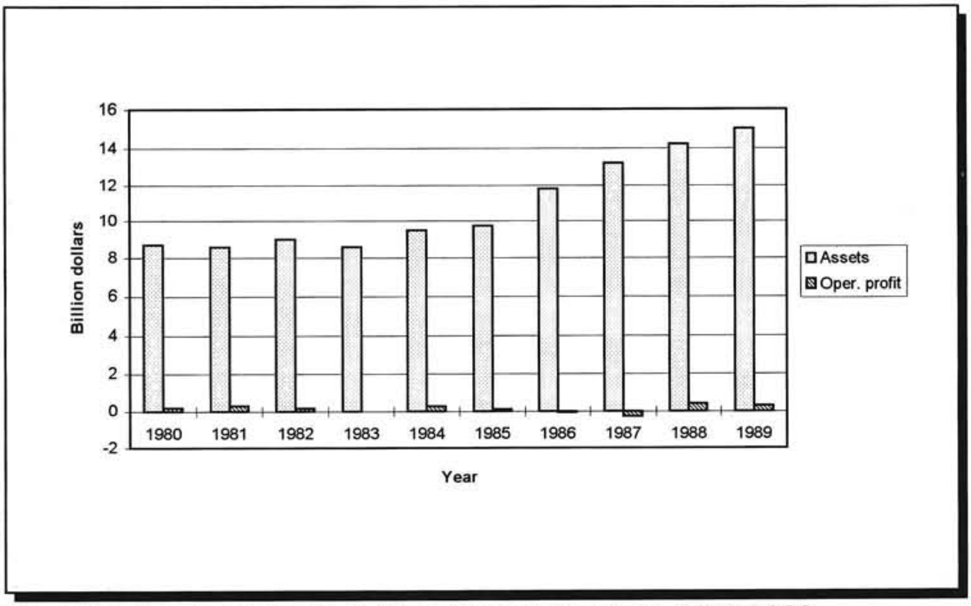


Figure 31: Return on assets of 10 major container lines, 1980-1989

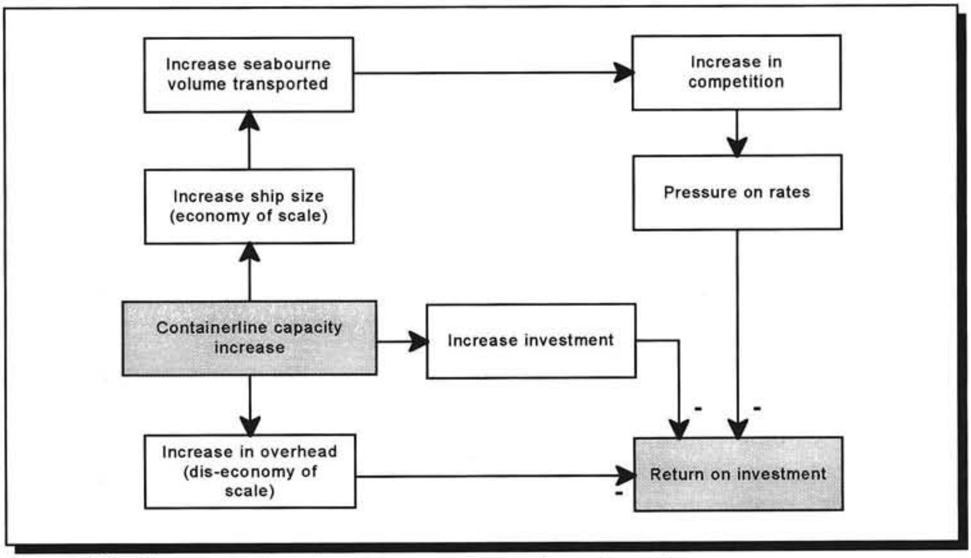


Figure 32: Counteracting forces on return on investment

necessitate a large international company structure. It is therefore very simple to establish a small, new container line and expand its operation without increasing the overhead cost per TEU dramatically. However, when a company grows

beyond a certain size, its international offices multiply and (container) control systems, information technology, container booking systems, communications, etcetera, all become much more complicated and costly.
A medium size container line has to implement all the sophisticated systems at once, and at a considerable cost without having the container volume. First after a strong growth phase, these large investments will pay off. In this intermediary phase, related to company size (in number of slot-terms), there seems to exist a dis-economy of scale. The causal diagram (**Figure 32**) shows that the negative forces on the return on investment, come from three different directions: increase in overhead cost, increase in ship investment (economy of scale objective), and a decrease of freight rates. The latter factor is important, as economies of scale benefits generated by the larger ships, are directly passed on to the customer, the shipper and receiver of cargo. Excess capacity leads to a continuous downward pressure on rates.

Container industry structural change

The above described effects are reflected by the structural changes, which are visible in the container industry. The number of container lines in the world is approximately 600, which is rather constant over the period 1984-1991. There are many small lines with less than 5,000 slots capacity (approximately 450), and middle group of some 100 companies with 5,000 to 30,000 slots, and a small group of some 40 lines with capacities above 30,000 slots. **Figure 33** illustrates the development of the number of companies in each size class over the period 1984-1991, and **Figure 34** the corresponding share in total slot-capacity.

Because of the dis-economy of scale effects, container lines have actually two options: stay small, or grow big very fast. If they stay in the middle, they risk to become 'sitting-ducks' that will be shot off by competition. This trend can be noticed already in the **Figure 34**, but a more recent update would confirm this dichotomy in the structure more clearly.

The bottom line of this analysis is, that the strategy of cost leadership is in principal the only option available to container lines, but only those companies with deep pockets can afford it in the long run. Most of the lines will have to sustain more years of negative cash flows before there is light at the end of the competitive tunnel.

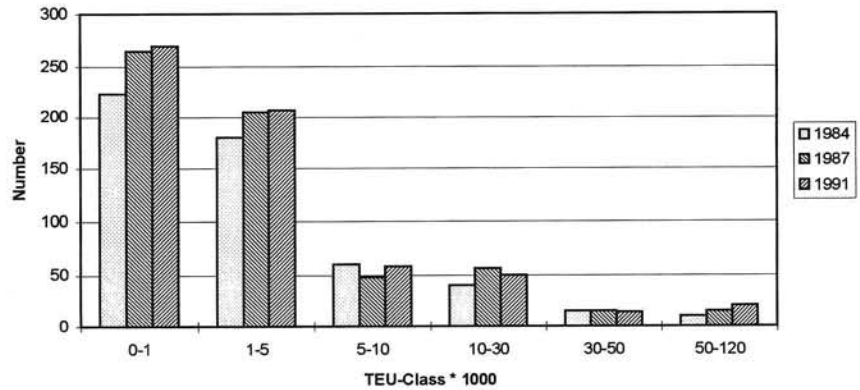


Figure 33: Number of container lines, 1984, 1987, 1991

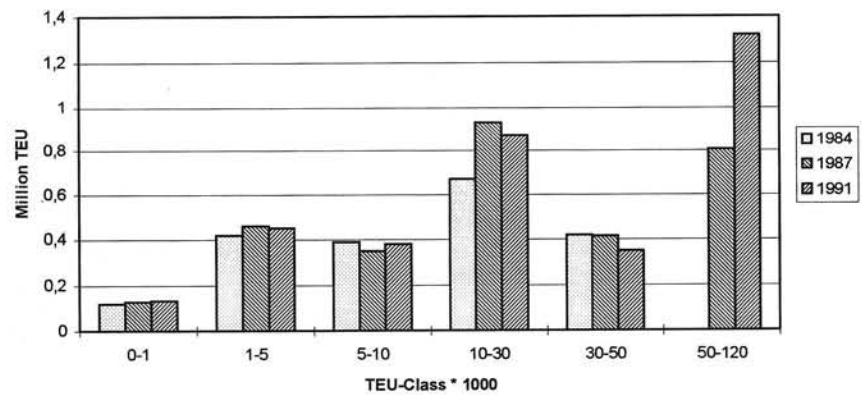


Figure 34: TEU-capacity of contianer lines, 1984, 1987, 1991

CHAPTER 12: MANAGEMENT OF INNOVATION AND BUSINESS SYSTEMS ENGINEERING

12.1 Pursuing fast-paced innovations

Management of innovation is complex but essential for the survival of the firm in the longer term. Structuring the management requires therefore some guidelines. T. Peters in *"Thriving on Chaos"*, outlines a business organisation that should be able to respond adequately to the need for firms to innovate. The management of innovations cannot be seen in isolation from the total strategy of the firm, as discussed before. There is no one answer or recipy to the challenge of innovation. Peters' fast-paced innovation recipy or prescription is schematically shown in **Figure 1**.
The ultimate goal of the prescriptions is *the creation of a corporate capacity for innovation* (bottom of figure); this is achieved by explicit *management tactics to encourage innovation*, which in turn leads to *four key strategies, which ultimately will result in the guiding premise*: Invest in applications-oriented small starts! These successive prescriptions will be discussed in reversed order.

1. Invest in applications-oriented small starts

Markets continue to splinter, technology continues to turn product and service development on its head. New competitors keep appearing, it is important to:

- Develop an innovation strategy that is marked by an explosive number of lightning-fast small starts that match the environments turbulence;
- Aim most small starts at small markets;
- Maintain in most small starts an application (customer) focus, rather than overemphasizing giant technological leaps;
- Mount completely independent teams that attack and make obsolete our most cherished (and profitable) product lines and services - before competitors do;
- Treat each would-be, new, or old product as an experiment to be constantly modified;
- Decentralise - modest-sized, independent business unit *is* a small start.

Speed, numbers, and a focus on application - that must become the new innovation formula, driven by accelerating market change. Lots of small, application-oriented starts, quickly expanded or quickly snuffed out, should be occurring in every organisation, large or small, manufacturing or service.

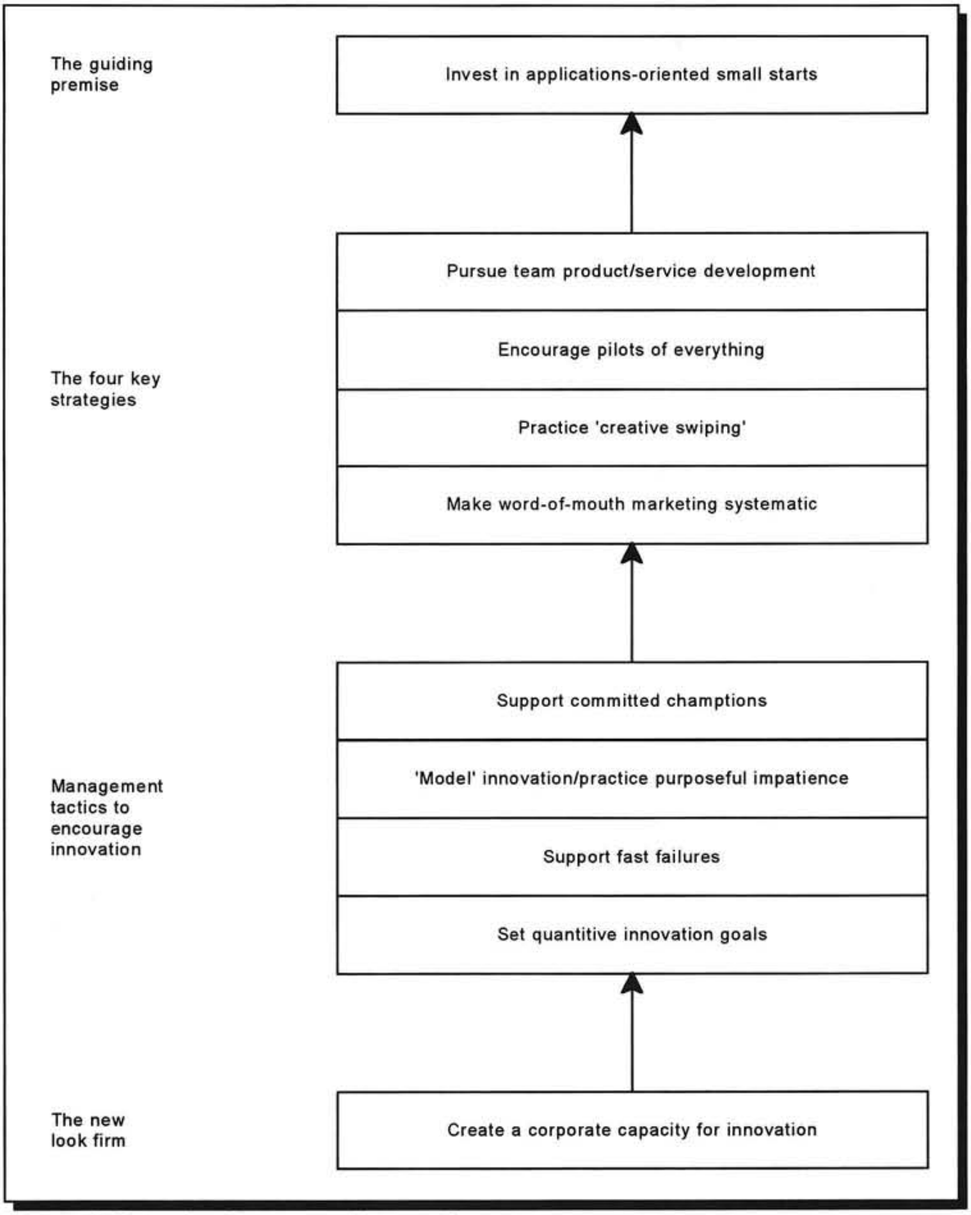


Figure 1: Persuing fast-paced innovation

2. Pursue team product/service development

To speed new product/service development to a pace approaching that dictated by new market needs, it is important to:

- Use multifunction teams for all development activities;
- Staff such new product/service development teams almost from the outset with full-time people from all primary functions - e.g. design/engineering, marketing, manufacturing/operations, finance, and perhaps field sales/service and purchasing;
- Involve outsiders - suppliers, distributors, and customers - in new product/service development from an early date as well;
- Be especially aware of the trap of 'shared resources' - that is, partially committed people or facilities.

The use of multifunction teams is the chief tool for speeding up product development.

3. Encourage pilots of everything

With ever more confusion in the market, it becomes increasingly important to replace talk with tests. It is important to:

- Substitute pilots and prototypes for proposals;
- Find trial sites and field champions or new programmes/projects/products as far from headquarters as possible.

Piloting rather than the constant rehashing of abstract proposals, must become a way of life. We need to dramatically speed up the first test or partial test of the first prototype, subassembly, store within a store, training module, software subsystem, pretest market.

4. Practice 'creative swiping'

In today's ever-accelerating business environment, it is important to put the 'Not Invented Here' syndrome behind you - and learn to copy (with unique adaptation/enhancement) from the best! Do so by aggressively seeking out the knowledge of competitors (small and overseas, not just tired old foes) and interesting non-competitors.
Become a learning organisation. Shed your arrogance - "*if it is not our idea, it cannot be that good*" - and become a determined copycat/adapter/enhancer.

5. Make word-of-mouth marketing systematic

Since the exploding array of new products and services is causing more and more confusion in the marketplace, and in the minds of early buyers of industrial or consumer goods, it is important to organise new product/service marketing efforts around explicit, systematic, extensive word-of-mouth campaigns. Purchasers buy the new products principally upon the perceptions of respected peers who have already purchased or tried the product.

6. Support committed champions

To match the accelerating rate of change in the environment, numerous innovation projects must be mounted, which requires to:

- Encourage as many 'determined beyond reason' champions to come forth;
- Accept some level of champion-induced disruption, far beyond the traditional norm;
- Draw out champions in personnel as well as engineering, around the edges of big and well-planned projects as well as independent ventures.

Any innovation project, whether in accounting or in new-product development, has low odds of success. We must learn to cherish those with a passionate enough attachment to a new idea to push for it, though most such people will be rough around the edges and most of the projects will fail.

7. 'Model' innovation/practice purposeful impatience

To get the constant innovation necessary for survival, it is important for managers to:

- Personally symbolise innovativeness in their daily affairs;
- Seek out opportunities to stand foursquare with innovators.

Seeing is believing! Would-be champions will be encouraged to come forth when senior managers demonstrate, by their actions, that they support constant innovation, even when it's a bit disruptive. It is essential that managers make a constant effort to recognise innovators (and applaud the details of their victories over organisational inertia), at all levels and in all functions.

8. Support fast failures

To speed action-taking - and reduce innovation cycle time - as necessary to be competitive requires us to make *more* mistakes, *faster*. Managers must therefore:

- Support failure by actively and publicly rewarding mistakes - failed efforts that were well thought out, executed with alacrity, quickly adjusted, and thoroughly learned from;
- Actively and publicly reward defiance or our own often inhibiting regulations;
- Personally seek out and directly batter down irritating obstacles - often as not small ones - that cumulatively cause debilitating delays and which champions cannot readily clear from their own paths.

Inaction is the chief enemy of speedy innovation. These prescriptions as a whole, are designed to induce faster action-taking. Peters gives an appropriate maritime illustration (**Figure 2**) in his book on the subject of managing risk-taking. "*You can try anything, as long as it's above the waterline*"; above the waterline meant anything that did not affect the basic integrity of the organisation. Some companies place the waterline very low (A), which means that they encourage managers to try anything; other companies place the waterline high (B), with the implicit message 'experiment' (and risk failure) as long as the issue is trivial.

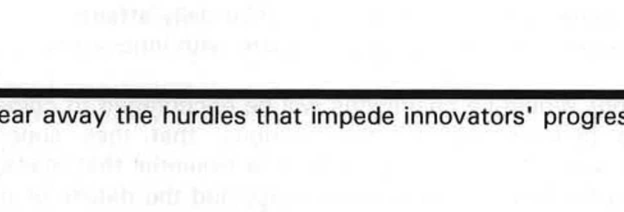


Figure 2: Clear away the hurdles that impede innovators' progress

9. Set quantitative innovation goals

Since a stepped-up rate of innovation has become essential, it is important to measure innovation. What gets measured gets done. While there are difficult issues of specification and definition, innovation can be measured. Even imperfect measures provide an accurate strategic indication of progress, or lack thereof.

10. Create a corporate capacity for innovation

The turbulent marketplace demands that managers make innovation a way of life for everyone. Therefore they must learn - individually and as organisations - to welcome change and innovation. The corporate capacity for continuous change must be dramatically increased.

12.2 Mentality and turbulence

The previous is, however, often easier said then done. Ansoff in Implanting Strategic Management outlines some of the psychological obstacles for such a positive attitude towards change and innovation.
As managers respond to environmental stimuli, they encounter successes and failures. Over time, accumulation of the successes forms a conviction in the manager's mind about 'things that do work', and failures build a conviction about 'things that do not'. Together, the two sets of convictions evolve into a success model of the environment, or what psychologists call a *mindset*.
Very few managers attempt to make their mental models explicit by writing it down, or programming it on a computer, but all experienced managers use such models in their daily decision-making work. These mental models are essential for managing in a complex and changing environment. But it remains valid only so long as the variables and relationships in the environment remain unchanged.
Whenever the environment undergoes a discontinuous change, as it did during the transition from the mass production to the mass marketing era, the manager's historical success model becomes the major obstacle to the firm's adaptation to the new reality. The manager's mental filter will eliminate novel and weak signals, which are not relevant to his historical experience, and thus fail to perceive the shape of the new environment, the newly important variables, new relationships, and new success factors.

This leads to a widely observable paradox that is described in the phrase: "*success breeds failure*" in a turbulent world. Thus the manager's success model becomes a second mental filter that is applied to the incoming environmental signals. **Figure 3** shows the schematic representation of this filtering process of management information. The model shows clearly the phase called 'perception'. This concept will be frequently discussed in **Chapter 21**.

Figure 4 shows the link between the level of environmental turbulence and the managers mentality necessary to stay in the business. It is evident that the more a marketplace is turbulent and surprising, the more creative and flexible a manager should be.

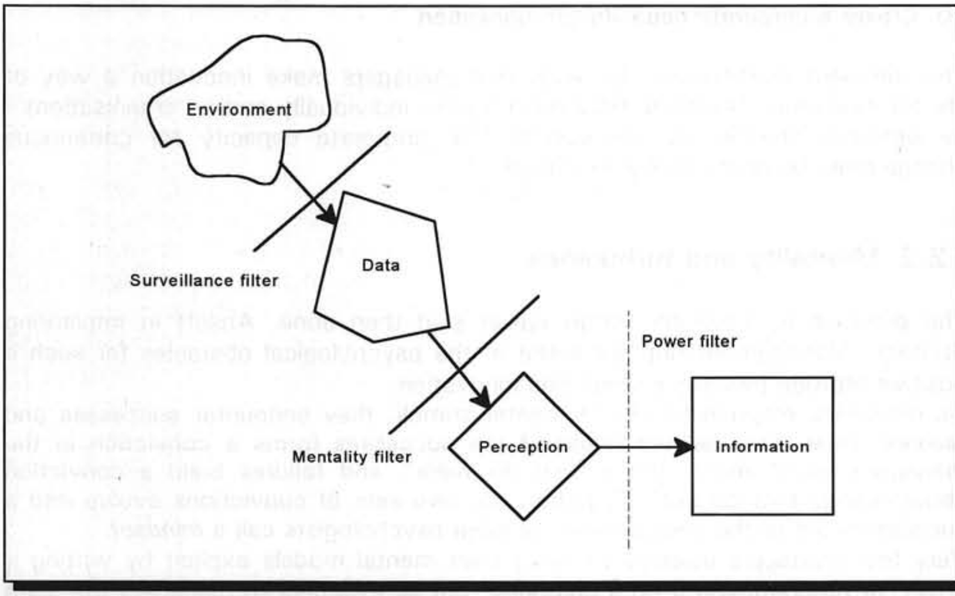


Figure 3: Filtering process of management information

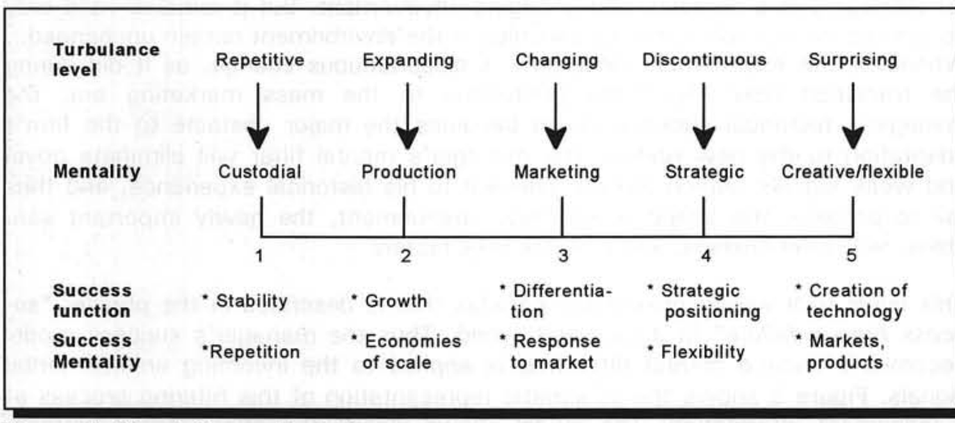


Figure 4: Mentality and turbulence

12.2.1 Innovation in the value chain

Management of innovation is not restricted to a few activities of the firm, like the R&D department, but to all the discrete activities a firm performs in designing, producing, marketing, delivering, and supporting its product or service.
Each of these activities can contribute to a firm's relative cost position and create a basis for differentiation.

A systematic way of examining all the activities a firm performs and how they interact is necessary for analysing the sources of competitive advantage and the potential for innovation. Porter introduces hereto to concept of the *value chain* as a basic tool for doing so. The value chain disaggregates a firm into its strategically relevant activities in order to understand the behaviour of costs and the existing and potential sources of differentiation.
A firm's value chain is embedded in a larger stream of activities that Porter calls the value system (**Figure 5**). Suppliers have value chains that create and deliver the purchased inputs used in the firm's chain; products pass through value chains of channels on their way to the buyer; products eventually becomes part of the buyer's value chain. Gaining and sustaining competitive advantage - through innovation - depends not only on the management of innovation - but foremost on the understanding of the firm's value chain and in particular how the firm fits in the overall value system.

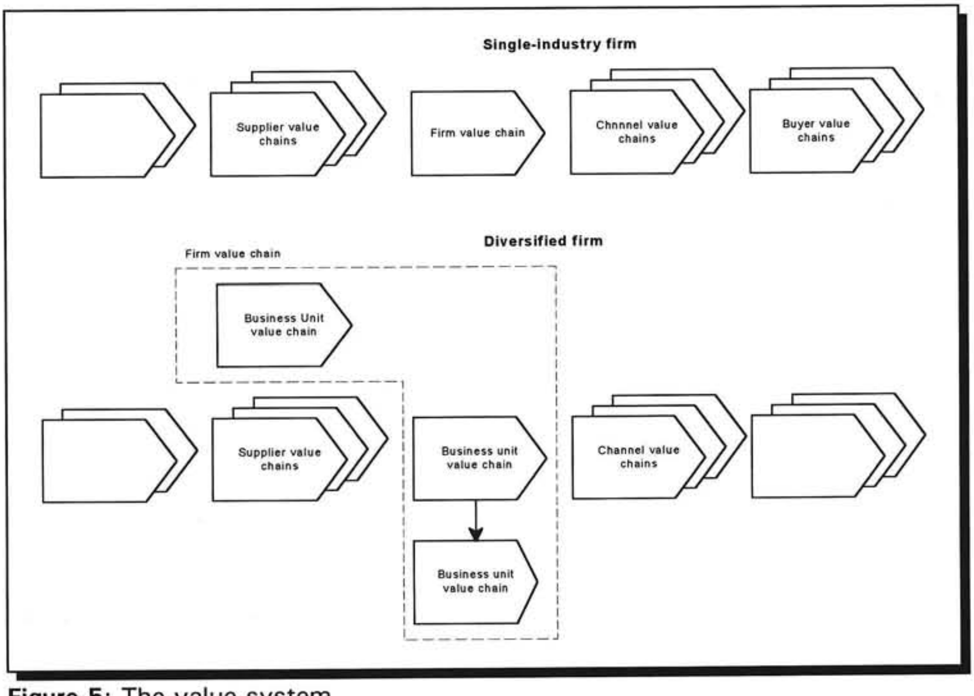


Figure 5: The value system

Porter's model provides the managers in the firm with an important new mental model for structuring innovation, especially if he looks at the more generic value chain of the firm (**Figure 6**).

The relevant level for constructing a value chain is a firm's activities in a particular industry (business unit). Though firms in the same industry may have

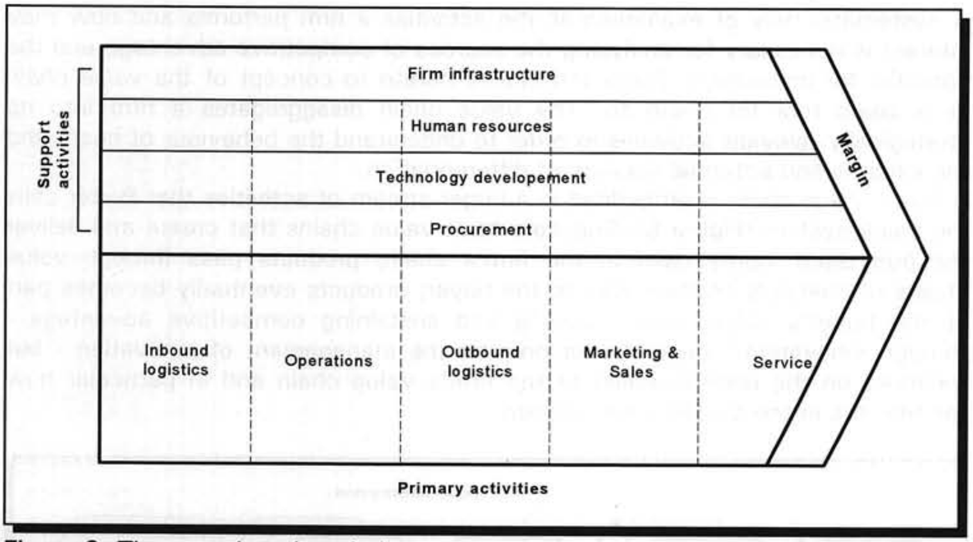


Figure 6: The generic value chain

similar chains, the value chains of competitors often differ. In competitive terms, value is the amount buyers are willing to pay for what a firm provides them. Value is measured in total revenue, a reflection of the price a firm's product commands and the units it can sell. A firm is profitable if the value it commands exceeds the costs involved in creating the product. Creating value for buyers that exceeds the cost of doing so is the goal of any generic strategy.

Value activities can be divided into two broad types, *primary* activities and *support* activities. Primary activities are involved in the physical creation of the product and its sale and transfer to the buyer as well after sale assistance. Support activities support the primary activities and each other by providing purchased inputs, technology, human resources, and various firm wide functions.

One of the support activities, which is of particular interest to the engineer, is *technology development*. This consists of a range of activities that can broadly be grouped into efforts to improve the product and the process. Porter terms this category of activities *technology development* instead of research and development because R&D has too narrow a connotation to most managers.
Technology development tends to be associated with the engineering department or the development group. Typically, however, it occurs in many parts of the firm, although this is not explicitly recognised. It does not solely apply to technologies directly linked to the end product.
Technology development also takes many forms, from basic research and product design to media research, process equipment design, and servicing

procedures. It is important to competitive advantage in all industries, holding the key in some.

Technology development that is more focused on R&D, is well described in prof. L.A. van Gunsteren's *"Management of Industrial R&D"*. He proposes a classification of business identities that is based on the the basic questions:

- Are we an organisation of doers or thinkers; in other words, are we in a business of making or doing things, or are we in the knowledge business?
- Are we offering a product or a capacity to our customers?

Table I schematically shows the strategic consequence of this positioning; successful firms tend to fit in just one of the four quadrants, or have separated their organisational units in such a way that each one fits clearly into one quadrant.

	Doing/making	Thinking/knowing
Product	License Taker	License giver
Capacity	Technology jobber	Consultant

Table I: Classification of business identities

The position of the R&D Department is clearly shown in **Figure 7**, which represents the innovative internal business environment, according to B.C. Twiss. The figure integrates the work of various authors discussed before, such as Ansoff, Porter and Peters. In the **Chapter 21** the link will be made between the normal design methodology, used in product development and the search methodology used to find opportunities.

12.2.2 Nolan's innovation management

Nolan starts *"The Innovator's Handbook"* with a quote from Machiavelli: "*There is nothing more difficult to carry out, nor more doubtful of success, nor more dangerous to handle, than to initiate a new order of things.*"
Many managers would identify with Machiavelli, as they know from experience, that to innovate, to initiate a new order of things, to do something that has not been done before, is difficult and hazardous. It involves change, and change will almost certainly encounter resistance. It involves uncertainty, and with uncertainty comes anxiety. It involves the risk that things will not turn as expected, the risk of failure. Not surprisingly, such managers tend to be wary of innovation. Nevertheless, and in spite of all the experience to the contrary, Nolan believes that Machiavelli is wrong and that innovation is manageable,

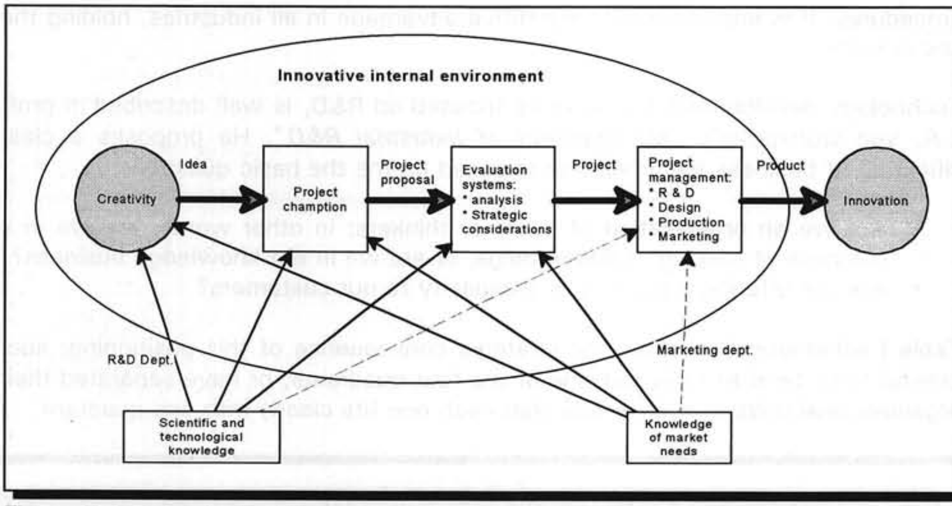
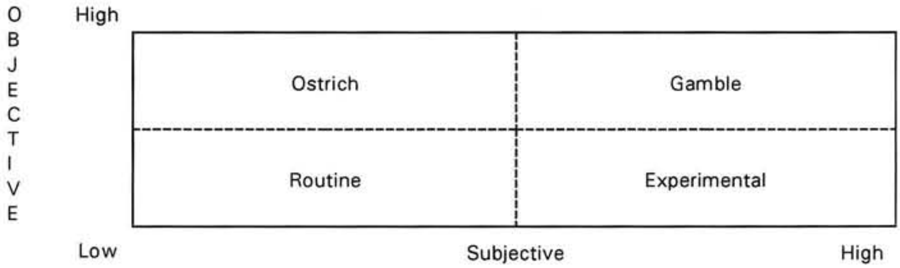


Figure 7: Technological innovation as a result of complex interaction

provided you know how to; you need the appropriate skills.
To be logical, analytical, orderly, decisive, right the first time, and aggressively single-minded are valuable qualities for dealing with one part of a manager's role - the efficient running of today's business.
To create the business of tomorrow, i.e. to innovate, and encourage innovation from others, calls for quite different qualities and behaviours, and these are the subject matter of Nolan's book. Probably the most important difference between innovative and routine management lies in the attitudes toward and the handling of risk. The risks of innovation are of two quite different kinds: alongside the risks of something actually going wrong in the real world, is the *emotional* risk of being criticised or blamed, feeling foolish or embarrassed. The interaction of the two types of risk (labeled objective and subjective) enables Nolan to identify four different categories of risky situations (**Figure 8**)

The well managed business operates mainly in the lower half of the diagram below, moving between Routine and the Experimental. It makes money from its routine activities; it innovates and safeguards its future through the results of its Experimental work. By contrast the business or individual who never experiments and continues to do things the way they are always done, feels safe and comfortable, but is in fact taking a big risk of being caught out by changing circumstances.
Because innovators are constantly learning from their experiments, they are likely to be very good at conservation, as well as innovation. By contrast, when the Ostrich type organisation finally bestirs itself to take the Great Leap Forward, it is likely to take the view "*we have been doing it all wrong - scrap everything and start afresh*", and throw away lots of babies with the bath water. There is no better place, according to Nolan, to start the process of



Low subjective/ low objective	Feels low risk, and is in fact low ris, because the familiar methods are still approprioate - call it *Routine*
High subjective/ Low objective	Feels risky, because it is something I have not done before, but even if it turns out badly, the outcome is tolerable and affordable, because it is a low risk experiment - call it *Experimental*
Low subjective/ high objective	Feels save, becuase it is familiar, but in fact it is high risk, becuase the situation has changed and the old way are no longer appropriate. Call it the *Ostrich* position
Low subjective/ high objective	Feels risky, and is in fact high risk. It is a *Gamble*

Figure 8: Catagories of risky situations

innovation at the behavioural level of the manager. The individual manager can do two things:

- Managing innovatively, doing his own job in new ways, and
- Managing for innovation, creating an environment in which creativity and innovative behaviour by others are encouraged and rewarded. The manager must have a personal risk-taking posture, and be equipped with a number of skills, in order to manage innovation successfully:
- *Problem solving*; to release the creativity that produces new ideas and new solutions, the raw material of innovation.
- *Communication*; to share understanding, knowledge and ideas through the organisation, and to exploit the opportunities created by communication and information technologies.
- *Teamwork*; to generate commitment, enthusiasm, tolerance and emotional support that is needed to sustain an innovative project through its vicissitudes.

Nolan illustrates the difficult path of innovation management with **Figure 9**. He concludes that it takes courage to stay with the vision during this period, to persevere, to maintain enthusiasm and commitment. The role of management is to supply that courage - to EN-COURAGE in the full sense of that word, where the EN prefix means 'to put into'.

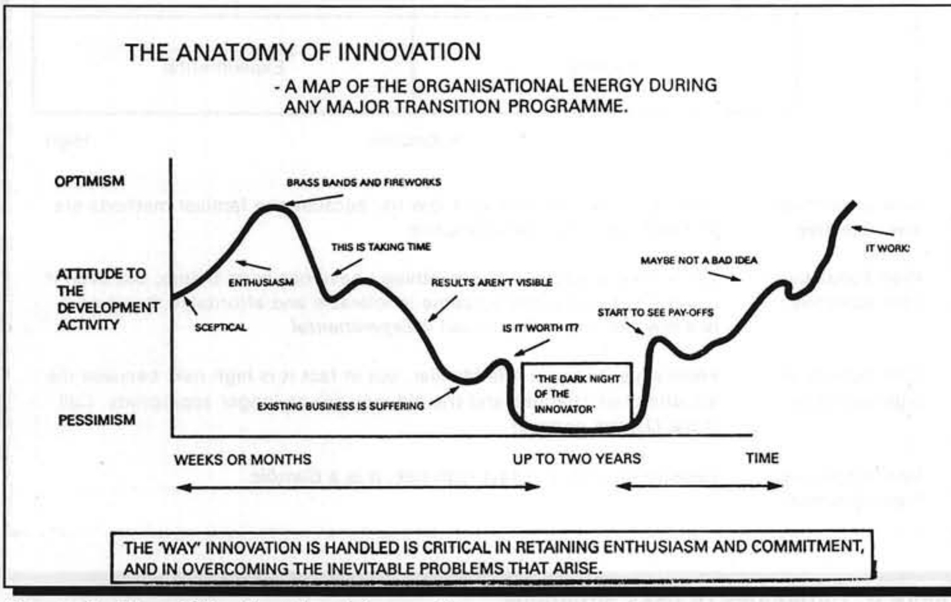


Figure 9: The difficult path of innovation management

12.2.3 Innovation management with Kværner

Very few maritime companies publish their research programmes. Usually, only the end product of much innovative labour is published in international journals. The Norwegian shipbuilding and engineering groep Kværner has published in 1995 its *Ship for the Future* programme, called Ship R3D. The brochure gives an interesting insight in the innovation strategy and the innovation management of the company. Kværner is the largest shipyard group in Europe and is located in a number of countries. Their research and development programme represents an investment of NOK 500 million and is organised around five challenges: technology, passenger, tanker, cargo and information highway.

The first four challenges form a cluster of sub-themes that are cemented together by the information highway challenge. The structure of the programme is shown in **Figure 10**. The shape of things to come out of this Kværner box of Pandora, is visualised in a number of artist's impressions from new ship designs.

The strength of Kværner is that its Ship R3D programme is based on an intimate knowledge of the shipowning and ship operation as well as the logistics of maritime transportation.

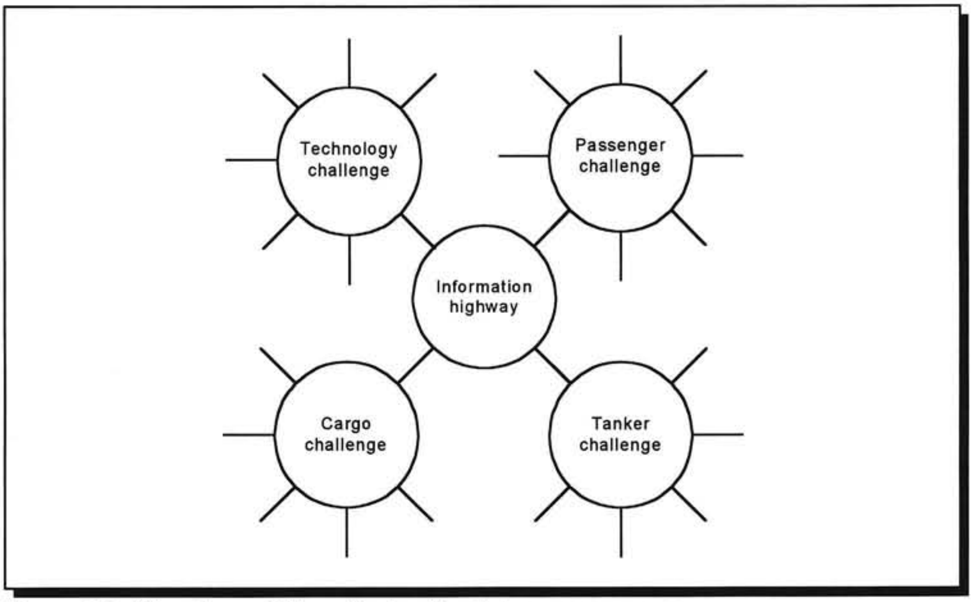


Figure 10: Structure of the ship for the future programme

12.3 Business systems engineering and concurrent engineering

Management of innovation requires sometimes a more radical restructuring of the organisation, known as Business Systems Engineering.

G.H. Watson defines in *"Business Systems Engineering"* the concept as follows: *"Business systems engineering is an approach to designing business processes in a structured way that maximises both customer value and enterprise performance."*

The approach to business transformation through systems engineering is illustrated in **Figure 11**. The driving forces in the model are two methods for determining the priority for engineering processes within the business system. The enterprise model is the result of a business modeling methodology that identifies critical business processes that need to be changed.

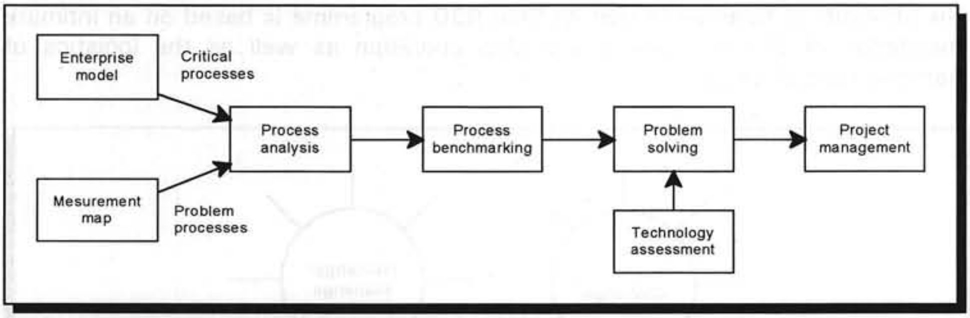


Figure 11: Business systems engineering model

The measurement map is the output of an analysis of the measurement requirements for the daily operations. During the process analysis phase, the customer requirements and business outcomes of the process are determined, and the process is documented for both sequence of events and measurement control points that may be used next for benchmarking. The process benchmarking studies should include comparisons with both internal and external partners. The problem solving model is used to structure the process-improvement project; the previous phases should have resulted in a clear problem statement. Technology assessment provides new concepts about the application of alternative technologies that may be used to generate the set of potential solutions.
The outcome of the problem solving process is the definition of a high-priority project that is managed to completion using such projects methods as critical path determination and management milestone reviews. **Figure 12** shows the business system engineering process in detail.

Concurrent engineering

Management of innovation has been discussed from different perspectives. The most radical one, which is based on Business system engineering implies a complete rethink of the way the firm operates. There are however less radical concepts, which achieve a similar effect at the product and process development level. This approach is called *concurrent engineering*. The essentials of this approach to innovation management will be discussed.

12.4 Concurrent engineering

Concurrent Engineering is a relatively young branch of industrial engineering, which combines a number of qualities that are lacking in other design methodologies. This section is based on the book *"Concurrent Engineering; Methodology and Applications"*, by P.Gu and A. Kusiak (edit.).

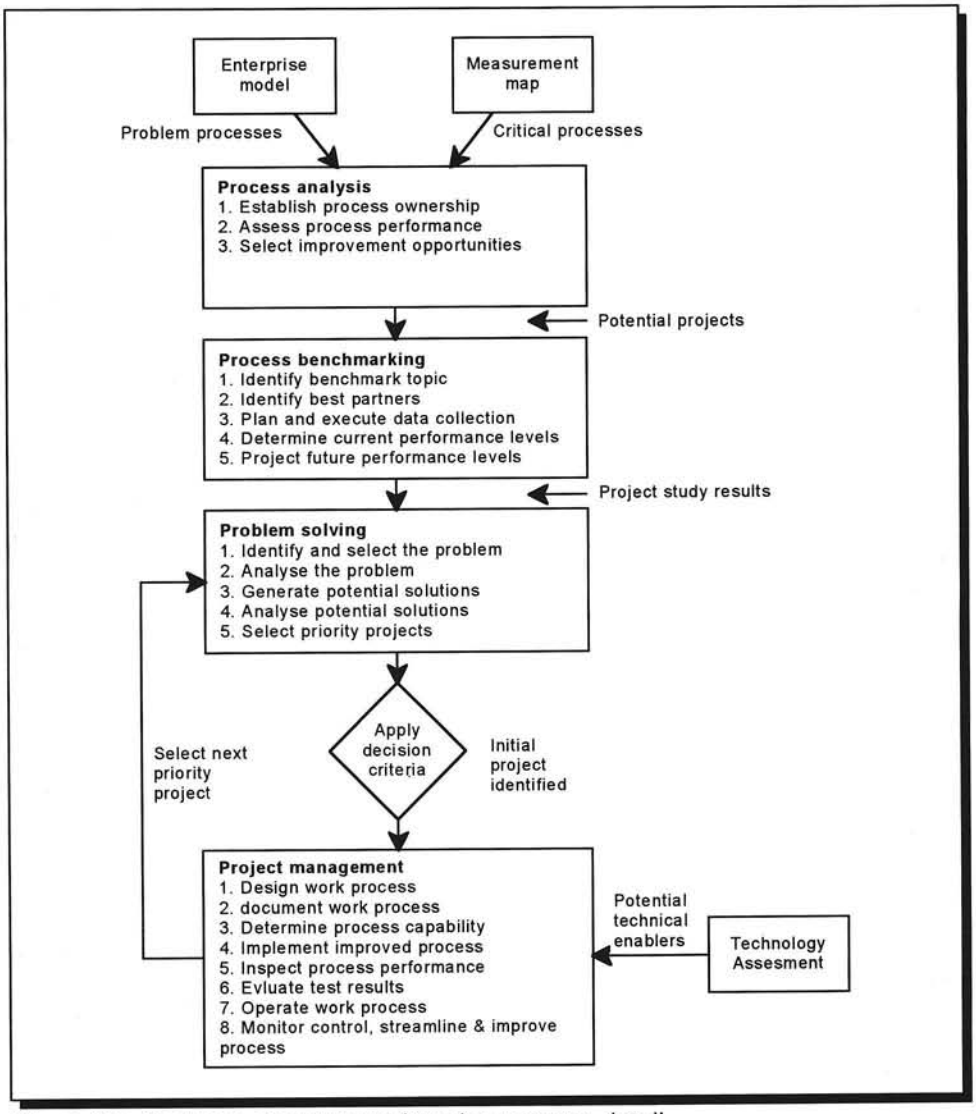


Figure 12: Business systems engineering process detail

The growing global competition in product-oriented industry has forced manufacturing enterprises to continuously improve product quality, functionality, and features, as well as to reduce product cost and time to market. The traditional approach to product development and manufacturing is a sequential and iterative process that requires a substantial amount of time to evolve the product design from its initial configuration to the final product. Since 70 percent or more of the total product cost is determined in the design stages,

significant potential savings can be achieved by improving the traditional design practices.
Concurrent Engineering, also known as simultaneous engineering, or life-cycle engineering, is a systematic approach to the integrated concurrent design of products and their related processes, including manufacture and support. From the time that the need is recognised, the entire product life cycle will be explicitly considered. The idea that underlies concurrent engineering is intuitive: that design and development of a product, the associated manufacturing process, involving activities such as production planning, equipment selection, facility design and process planning, as well as the product service system, involving maintenance, marketing, distribution, and other organisational and management aspects will be considered.
In contrast to the traditional sequential, iterative and distributed design practices, the concurrent engineering approach requires a parallel, interactive and cooperative team approach to product and process design. In large-scale manufacturing systems involving a large number of resources and design activities, the clustering of those activities in the design process which might be scheduled simultaneously is an important step toward achieving concurrency, and can lead to savings and increased quality through simplification of the entire manufacturing process.

As the traditional, sequential approach keeps separate the product design, production, distribution, and field maintenance functions, the resulting engineering decisions tend to be myopic, and leading to a negative impact on the ultimate product quality and cost.

As already mentioned, in order to remain competitive in business, companies must shorten the product life cycle from conceptual ideas through design, engineering, manufacture, promotion, shipping and service. Compression of the entire manufacturing cycle is usually achieved through *re-engineering* of the manufacturing and business processes, by first eliminating non-value added activities in the processes wherever possible. This is followed by attempts in improving the efficiency of the remaining activities, which involves a close look at where concurrent engineering can best be applied to achieve parallelism in some processes. Also of interest are the improved exchange of ideas and identification of constraints regarding activities at a much earlier time in the process, thereby reducing rework time and cost, and resulting in higher quality products.

An example of a CE project is given in Watson's Strategic Benchmarking, the Ford Team Tauras, although he calls it competitive benchmarking. The conclusion that can be drawn from this is that the definitions like Concurrent Engineering, Benchmarking and Re-engineering (Business System Engineering) are overlapping. **Figure 13**. shows the organisational chart of the Team Taurus. The car product development group is responsible for overall direction, design, development, control and final approval. All the basic functions, like manufacturing, service, sales and marketing are organised as a spider's web.

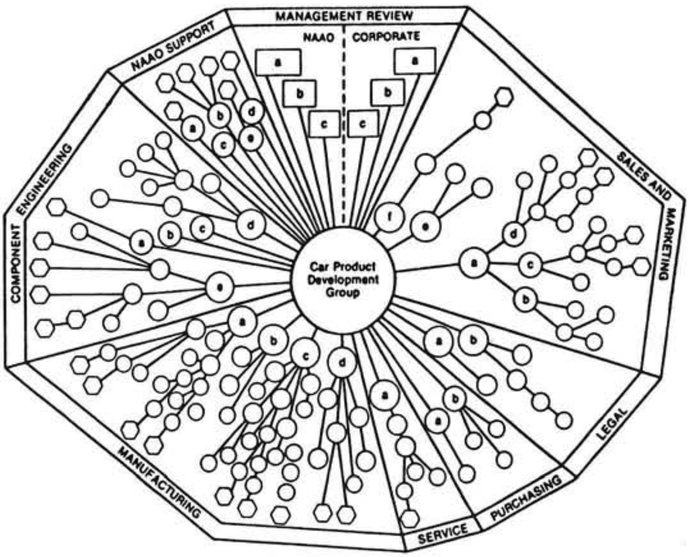


Figure 13: Team Taurus organisational chart

RACE

The barriers to concurrent engineering are mostly cultural, organisational, and technological in nature, according to H.M. Karandikar et al in Assessing Organisational Readiness for Implementing Concurrent Engineering Practices and Collaborative Technologies. A successful implementation of CE requires that these barriers be identified up-front. The Concurrent Engineering Research Centre has developed a model, a measurement tool, and a methodology - the Readiness Assessment for Concurrent Engineering (RACE) - to assist CE implementors in identifying the barriers and prioritising implementation actions. This RACE methodology will be discussed as it highlights the basic element of CE. The Centre proposes an organisational CE transformation strategy that comprises four stages: awareness, readiness, deployment and improvement, as shown in **Figure 14**.

The authors believe that CE readiness can best be conceptualised in terms of two major components: the product development process and practices, and technology. This latter element is important, as it fits in well with the technology assessment concept in the benchmarking process.

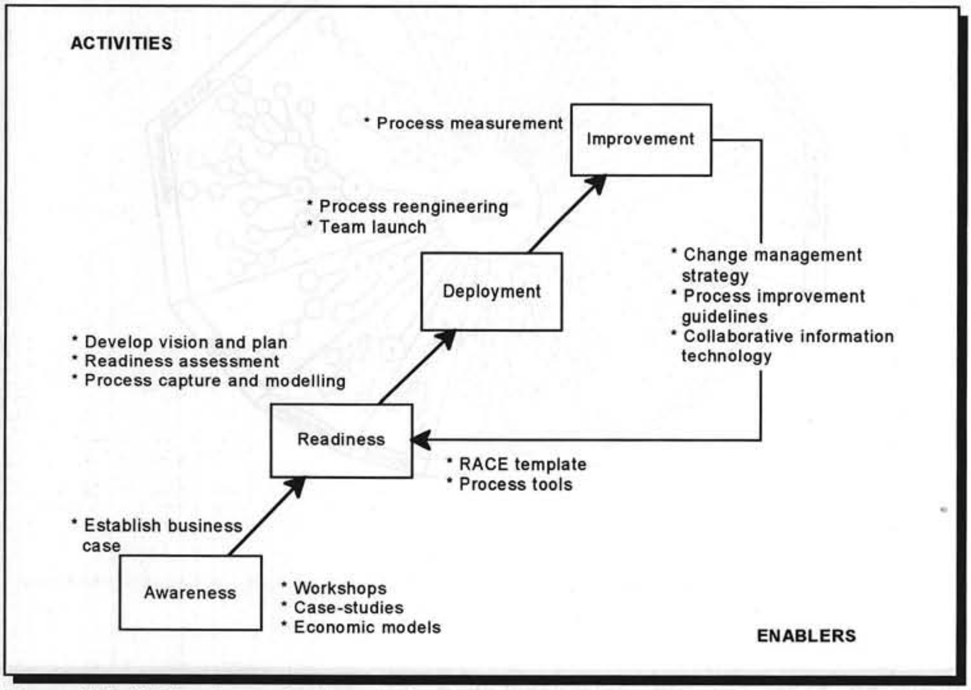


Figure 14: CE implementation strategy

The *process components* encompasses nine major elements, these are: customer focus, process focus, strategies for team formation and development, accommodation of teams within the organisation, management systems, mechanisms for rapid product assurance, agility, senior leadership commitment, and discipline.
The *technology component* covers five areas: application tools, communication, coordination, information sharing services, and integration.

Figure 15 shows the results of a Readiness Assessment for these two major components: Processes and practices, and technology.

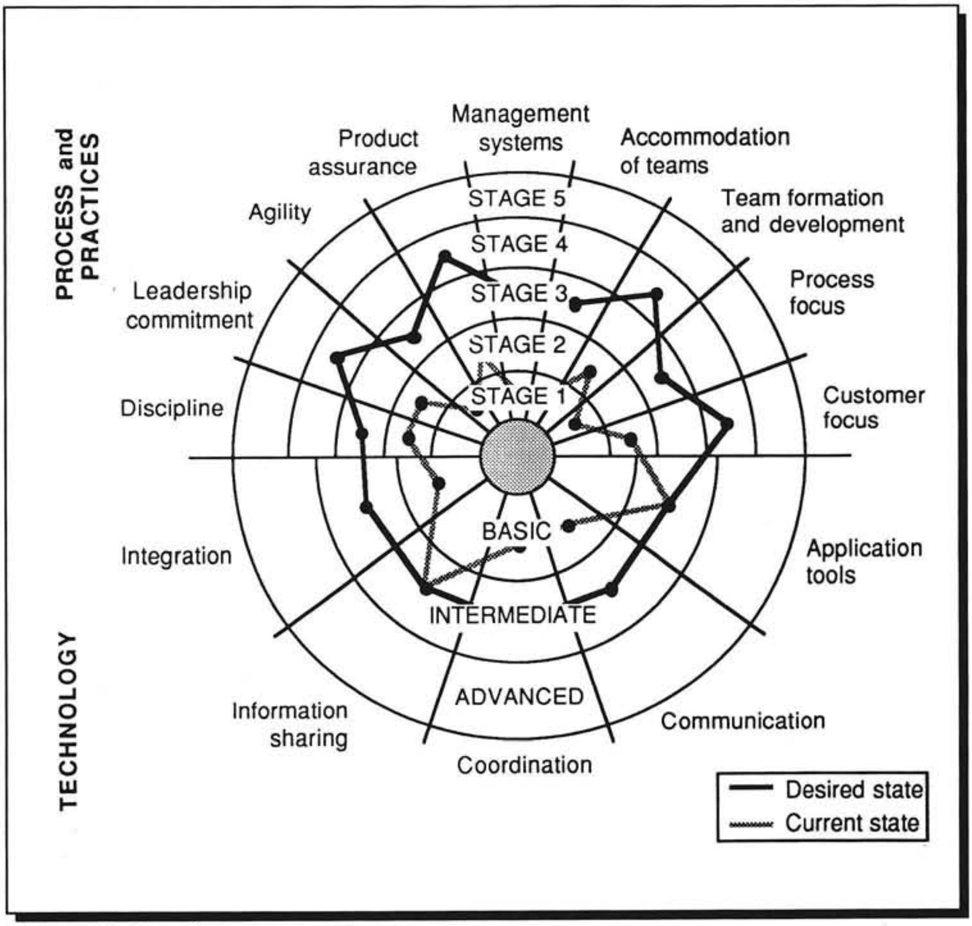


Figure 15: Readiness assessment results

Concurrent Engineering is an important tool to operationalise the Business System Engineering methodology, while at the same time incorporating the benchmarking methodology.
The application of CE for ship design is in principle ideal, but can be frustrated by the fact that the manufacturing component, is done by a separate entity, the shipyard. In the ideal world of ship design, the CE design team of ships should be a mixture of all the relevant disciplines. This aspect will be discussed in the final chapter on a new design innovation paradigm in shipping.

CHAPTER 13: DESIGN METHODOLOGIES

13.1 Introduction

1) Industrial design

Industrial design engineering at the Delft University of Technology is organised in a separate Faculty, which attracts many engineering students. At this Faculty *industrial design* is taught, and the basic ingredients of the curriculum are courses on design methodology. The basic design approaches, as described in the course material of the Faculty (N.F.M. Roozenburg, J. Eekels - *"Produkt ontwerpen, structuur en methoden"*) will be briefly summarised in this chapter.
Although the Faculty is involved in *industrial* design, its main focus is on consumer and the smaller capital goods. The large capitals goods, such as planes, cranes, ships, buildings and infrastructure (ports, etc.) are designed within the specialised Faculties within the University.

2) Aircraft design

At the Faculty of Aerospace Engineering, students learn the *design process of aircraft*. The design methodology used at this faculty will be discussed here, as it might give the naval architecture/marine technology engineer new insights in the design process of large capital goods.

3) General design methodologies: Creative problem solving and opportunity search

The design of ships has developed over the centuries into a distinct discipline, which is called *naval architecture*. In its traditional sense, this design methodology related more to the hardware design of the ship, than to its operations and commercial aspects. This book is intended to bridge that gap and to add a new aspect to the design process of ships, the opportunity search.
Most industrial design methodologies are based on trying to solve a certain problem. There are many problems in shipping, like in all economic sectors, that have to be addressed and solved. However, how do we bring positive change, in the absence of problems? Edward De Bono has drawn repeatedly attention to this aspect of creativity and innovation, especially in his book *"Opportunity Search"*.
The science underlying Creative Problem Solving (CPS), originates in the U.S.A. and many professionals there are involved in applying CPS in business and teaching it in the academic community. CPS has developed its own methodol-

ogy, which is very much similar to the industrial design methodology. The two will be discussed and compared.
Although that the CPS-methodology is more focused on opportunity search, its methodology has not be adapted to the specific needs of the shipping sector. Therefore, this book proposes the performance-trigger analysis, based on S-curves. Opportunities can be found by systematically analysing the key-performance indicators of the ship in relation to its logistical function. These triggers for finding opportunities and turning these into innovation, should be further put into a business environment perspective; they cannot be isolated from it. It is like the Gestalt-picture, shown in **Chapter 10**. Without the background (business context), the foreground (ship) cannot be seen. That is also the reason for the inclusion of several chapters on strategy and competitive advantage such as the conceptual models provided by Ansoff (environmental turbulence) and Porter (competitive advantage, value chain).

4) System dynamics

An other design methodology, in particular of more complex systems, is *system dynamics*. This approach facilitates the definition of new scientific concepts, and a holistic view on reality. System dynamics is at the basis of many new scientific developments during the last decades, as it stimulated the researchers to explore uncharted territory and at the same time use their individual creativity. This led to many scientific innovations, especially in the more complex, industrial, economic, biological and social systems. This chapter will briefly discuss this important design methodology.

5) Structured analysis

Structured analysis is based on a convention of formalising relationships between variables that make up a system. The convention, known as activity/factor (A/F) diagrams, is a systematic way to structure the analysis of a more complex nature. It is not as easy to use as system dynamics, especially in the early stages of concept development; users of A/F diagrams have a tendency of making these diagrams after they have completed the analysis, and use the A/F diagrams as a means of presentation, communication and verification in order to see that all the variables are properly related to one another. The case-study in **Chapter 22**, Decision support system for the planning of chemical tankers, illustrates the use of A/F diagrams in the shipping sector.

6) Benchmarking

Benchmarking is a tool to systematically measure performance in relation to the other competitors or industry standards. It is therefore not a design methodology as such, but rather a very useful tool to structure the relevant performance indicators of a system, product or service in the preliminary design phase and to create triggers for the design innovation process. The benchmarking methodology has already been illustrated with the help of two examples from the shipping sector, in particular the Panamax bulk carrier segment and the container ship segment.

13.2 Industrial design methodology

13.2.1 The strategic framework

Industrial design methodology should be seen in the framework of a firm's strategy, as proposed by Ansoff and Porter. This framework of product development within a firm is schematically shown in **Figure 1**. The basic building blocks of product development are a technical development process and a commercial development process. The latter one is shown in **Figure 2.** The technical development process in its simplest form is shown in **Figure 3.** In reality the process is of course more complex and an iteration of developmental steps, as shown in **Figure 4.** The total innovation process within the firm is schematically shown in **Figure 5.**

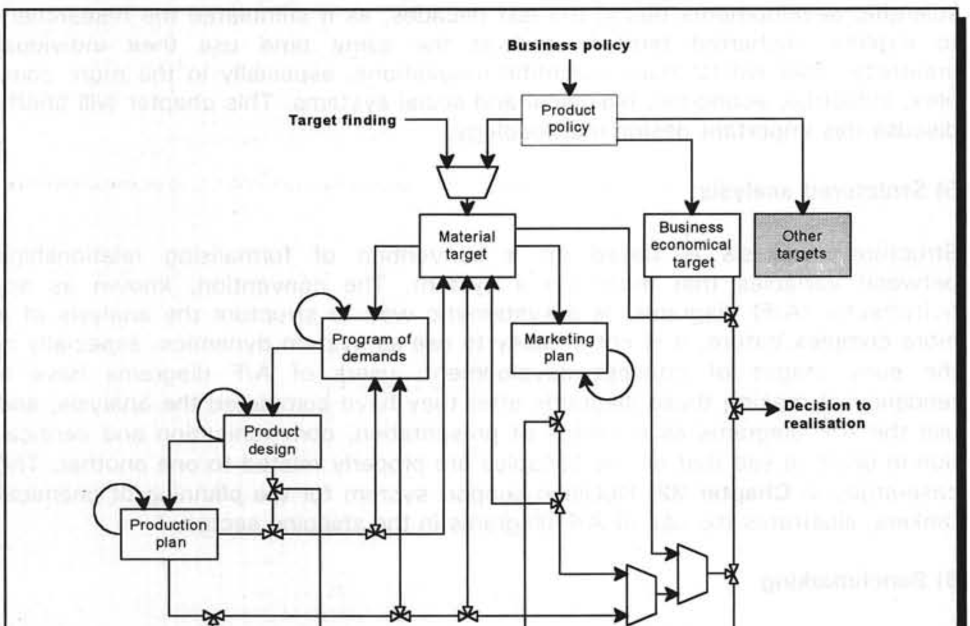


Figure 1: Product development

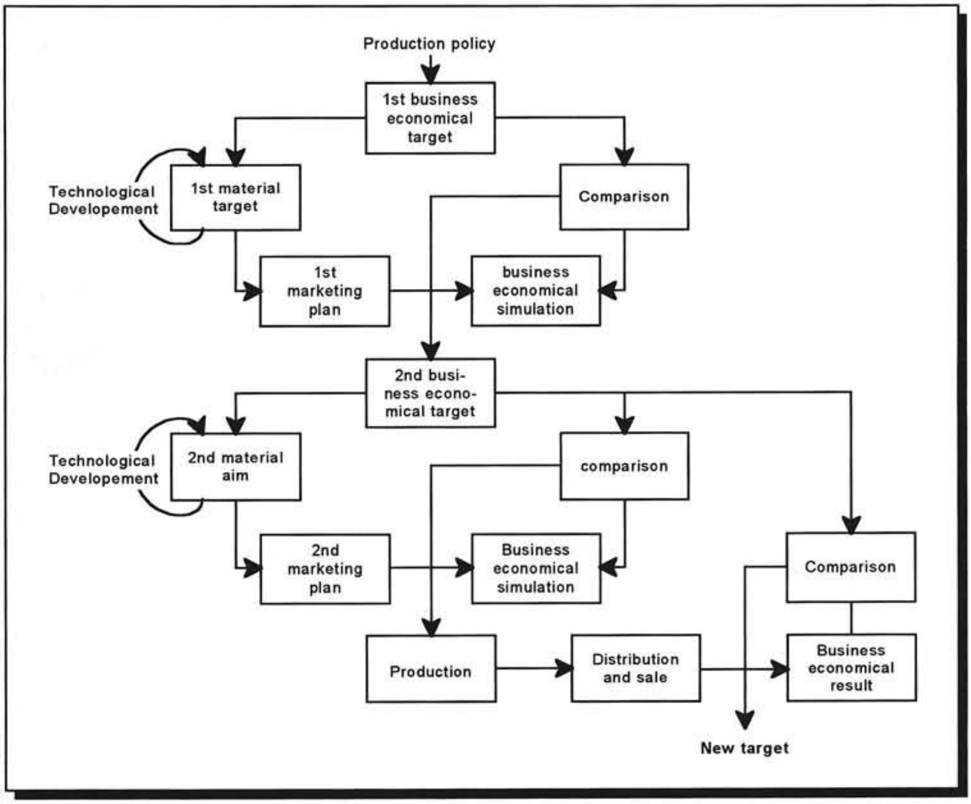


Figure 2: The commercial development process

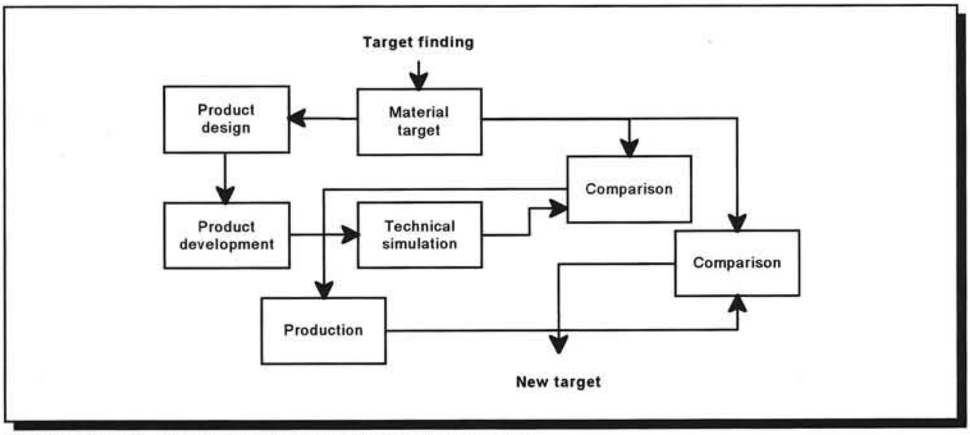


Figure 3: The technical development process

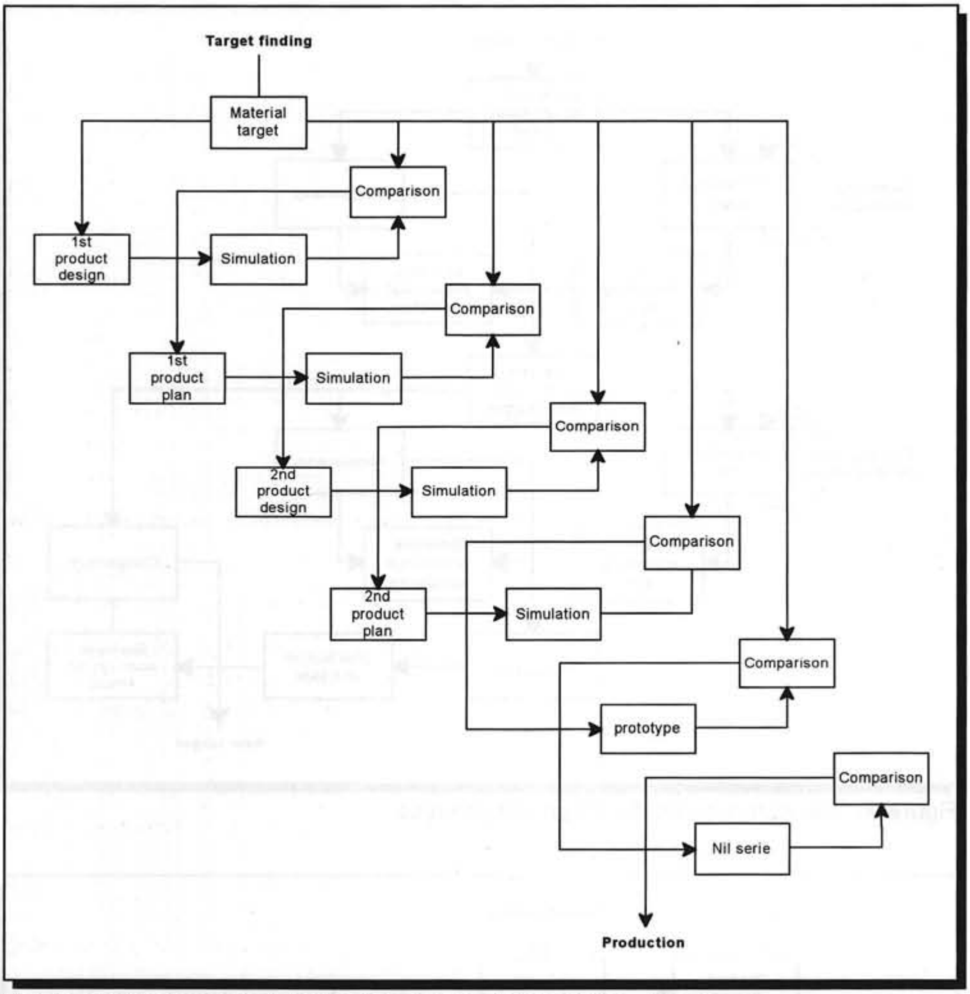


Figure 4: The technical development as an repetitive process

The key activities of the innovation process are: product planning, product policy, technical development, commercial development. These activities will be briefly discussed. Understanding the process and the key-activities is a necessity for understanding the the design methodology in a stricter sense.

- *Product planning*
  During this phase of the innovation process, it is decided which products to develop and when. In larger firms this involves often many product lines, which are grouped into a product-market plan. The selection of new ideas for products should be based on a market need and a technical concept. The product-idea is at the centre stage of the design process;

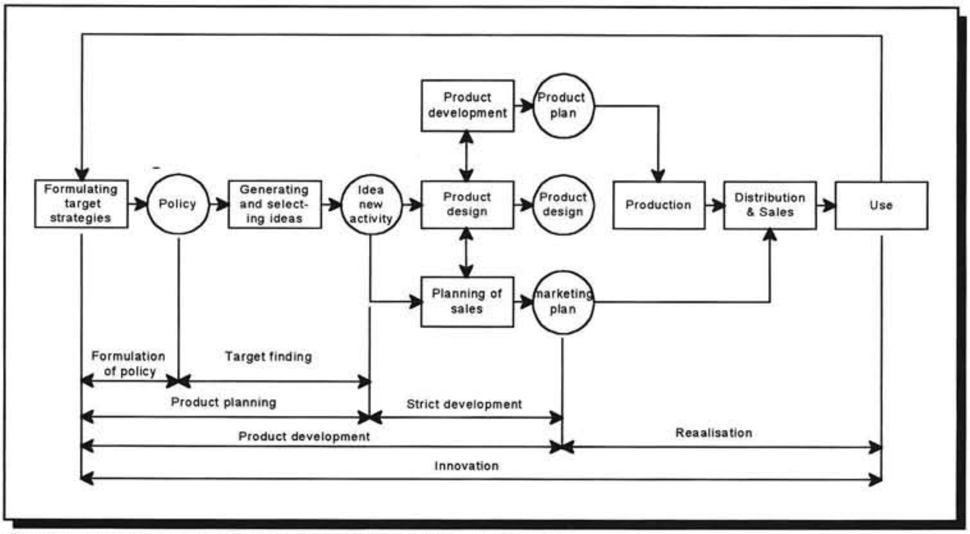


Figure 5: The phases of the innovation process

- *Product policy*
  Product planning is based on a product policy, which in turn is based on the firm's objectives and strategy. The definition of a product policy takes many constraints in consideration, such the R&D capacity, available funds (cash flow from operations), competitor behaviour, etc.;

- *Technical developmen*t
  During this phase, the material aspects of the production and the means of production are defined.

- *Commercial development*
  Projections of sales, price, distribution cost, etc. will result in a marketing plan, which is part of an overall marking strategy;

- *Management of product developmen*t
  The whole innovation design process is of course not linear, but iterative. The feedback from the different processes of design, production and marketing will constantly obliged the firm to readjust the original ideas. This is a difficult process, which may, if not well managed, lead to budget-over runs. Management of the process is an essential element in innovation.

13.2.2 Design methodology

General design methodology is the science of methods which can be or are used in the design process. The meaning of methodology is best described by: work rules or practical approach to problem solving. Relevant questions for design methodologies are:

- How is an efficient design process structured?
- How should the design process be tackled in order to be effective and efficient?

Design methodology attempts to provide the user with the conceptual tools with which he or she can structure and manage the design process effectively and efficiently. This requires knowledge of the design process itself, as well as the object knowledge on which the work is focused. Many design methods are not only specific for industrial or product design, they can be applied to other areas as well. This is clearly illustrated in this chapter.

The basic cycle of the design process is shown in **Figure 6** and **Figure 7**. The first figure shows the classic steps of analysis, synthesis, preliminary design, simulation, evaluation and acceptance/implementation. The second stresses the interactive, spiral structure of the design process. Within this basic cycle, three different phases can be distinguished:

- The definition of the product in system terms, the functional analysis and structure;
- The basic solution to the product-innovation;
- The material design of the product.

The last phase, the material design depends on many properties of the design characteristics, as shown in **Figure 8**. There are various ways to represent the three phase approach schematically. **Figure 9** shows the German engineering institute's approach. **Figure 10** shows the process of conceptual design, material design, and detailed design.

The book of Roozenburg and Eekels on product design contains a number of case-studies in which the industrial design methodology is clearly illustrated. One aspect, which is crucial in the design process - *creativity* - is implicitly assumed to happen in the design cycle. Creativity plays at two levels a role in the design process. At the pre-product level and in the idea-generation phase for new product concepts. The first question to answer is: can creativity in design be measured anyway?

H.H.C.M. Christiaans, in his doctorate thesis *"Creativity in Design; the Role of Domain Knowledge in Designing"* has investigated the creativity content in the design methodology used at the Faculty of Industrial Design.

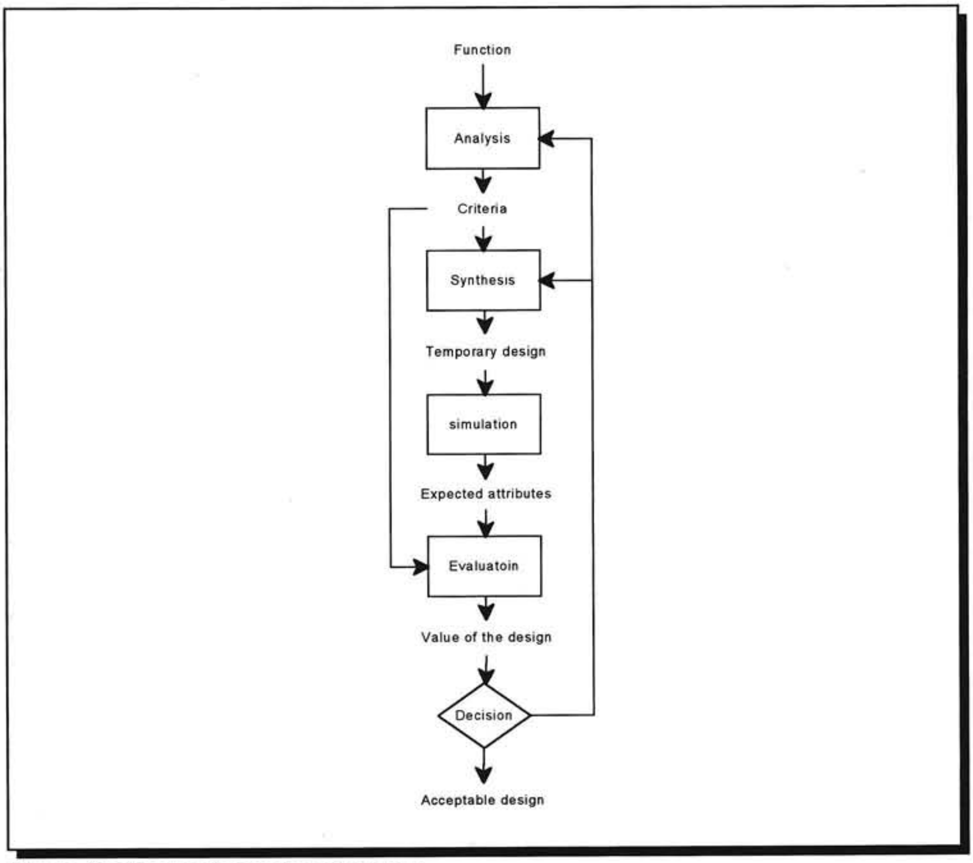


Figure 6: The basic cycle of design

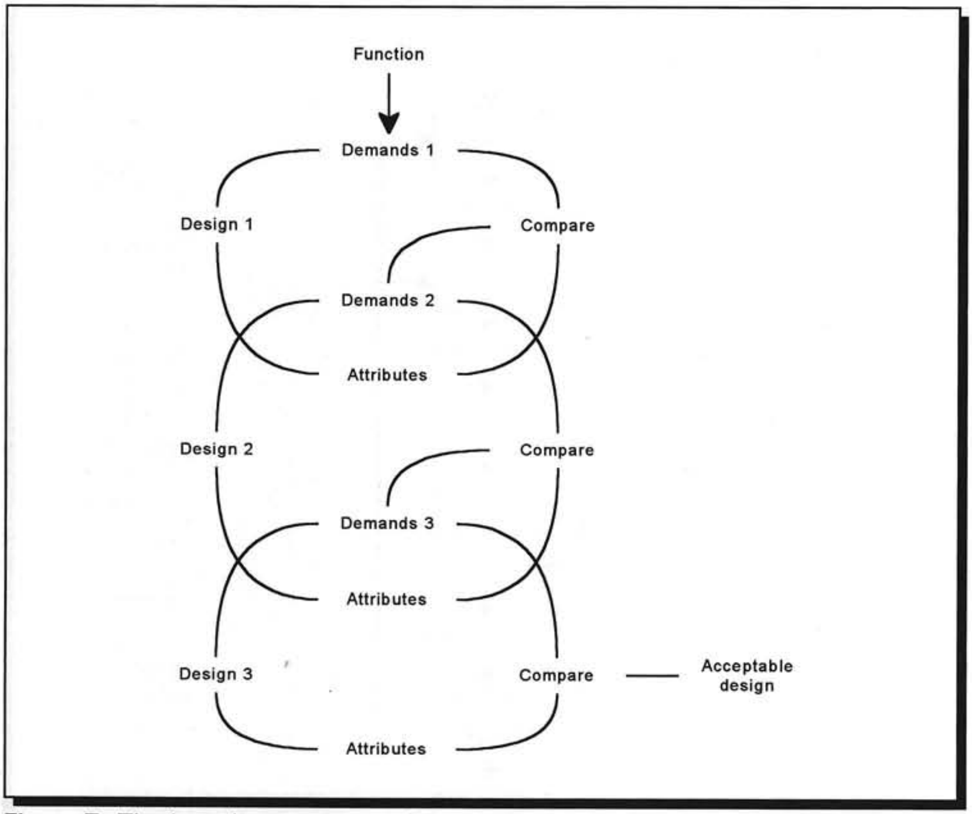


Figure 7: The iterative structure of the design process

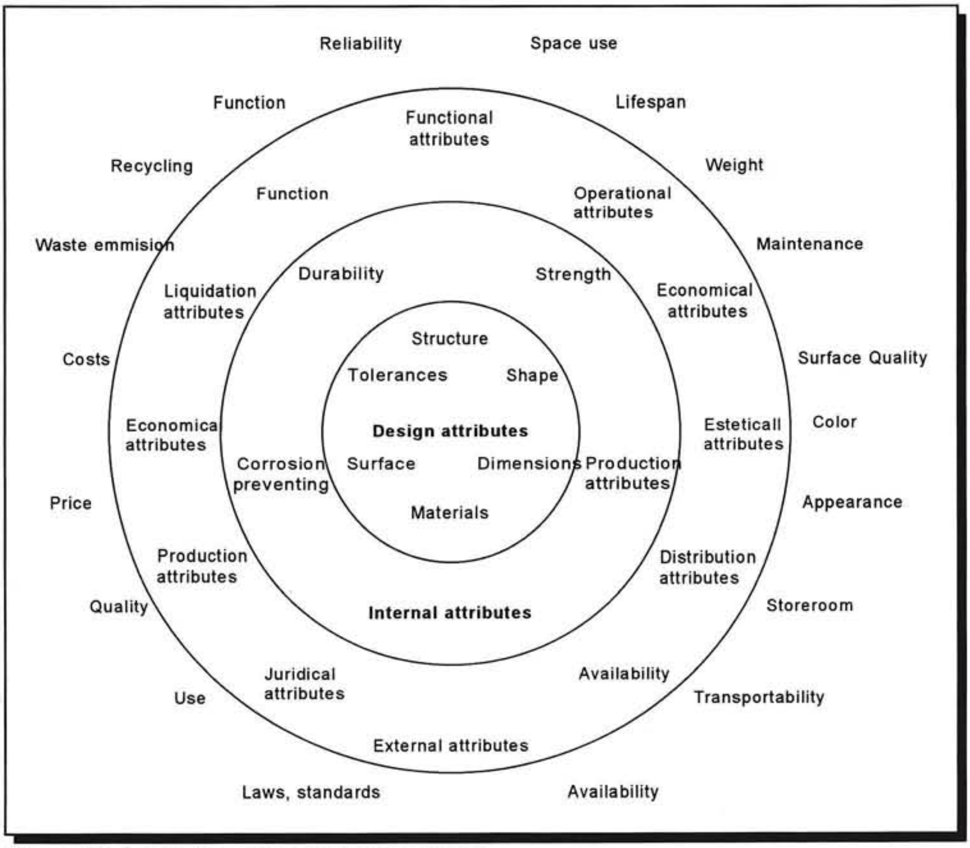


Figure 8: Attributes of technical systems

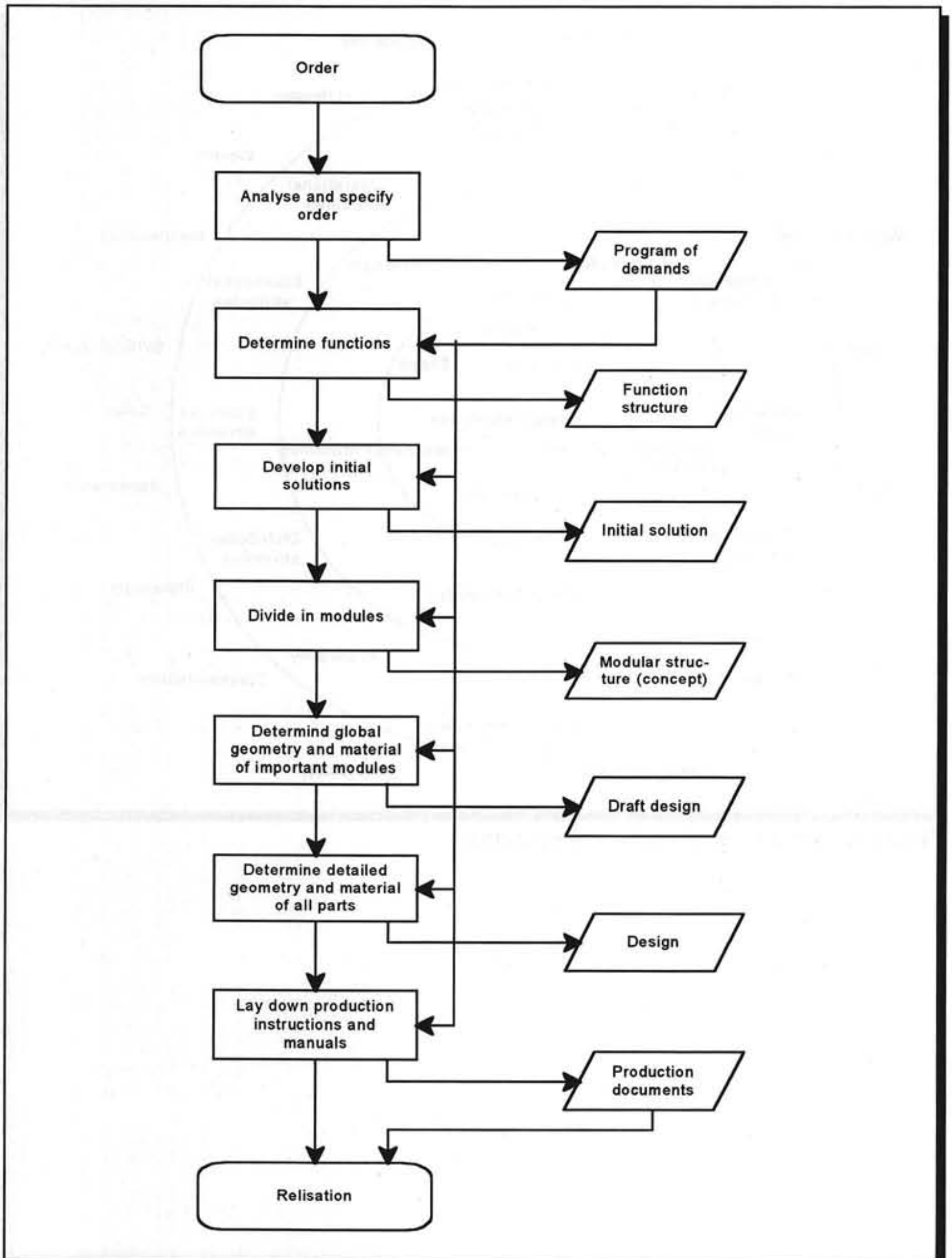


Figure 9: Phases of the design process according to VDI2221

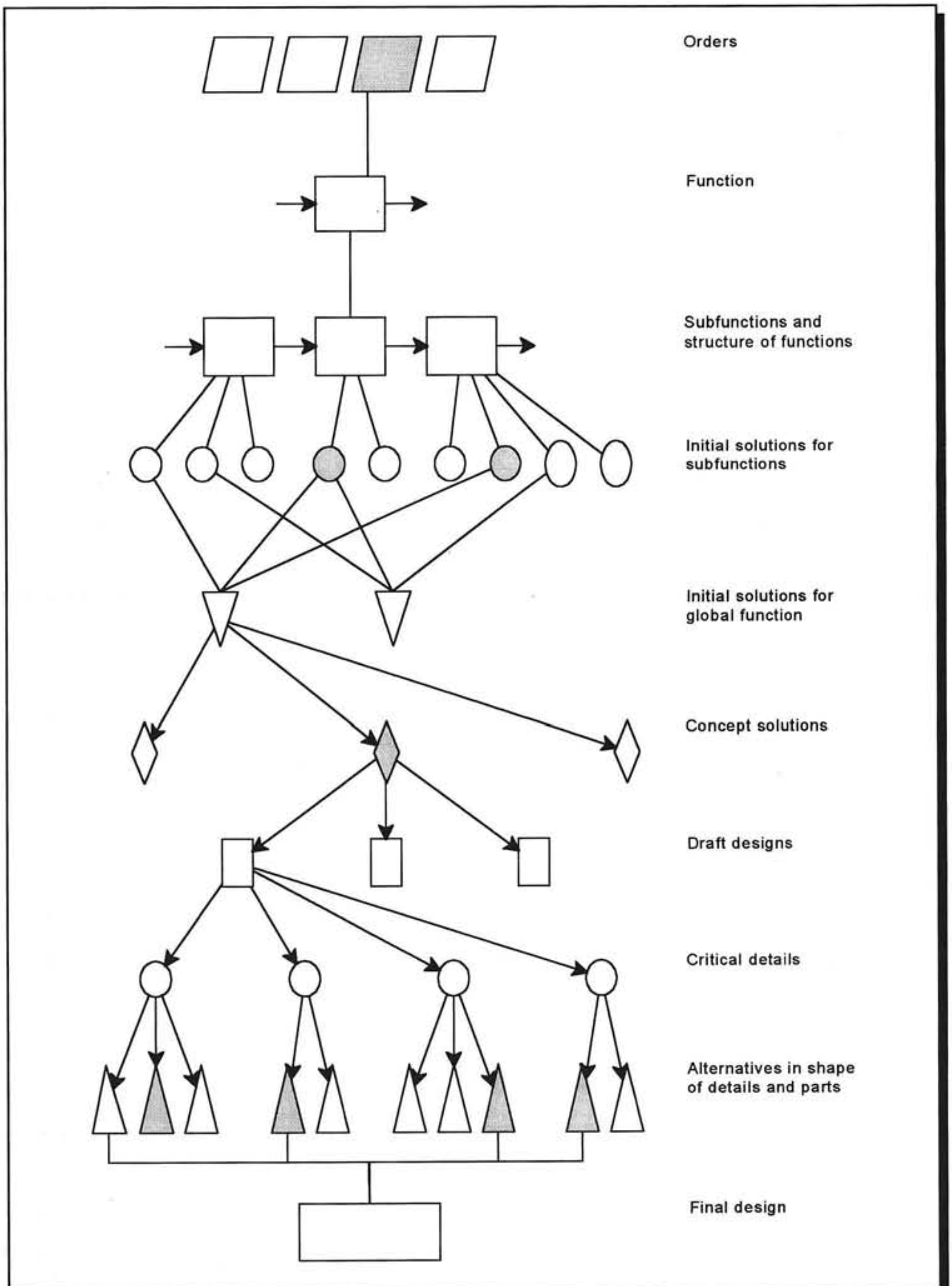


Figure 10: Process of conceptual design, material design and detailed design

He uses the components of creative performance and the componential framework of creativity developed by Amabile (**Figure 11** and **Table I**).

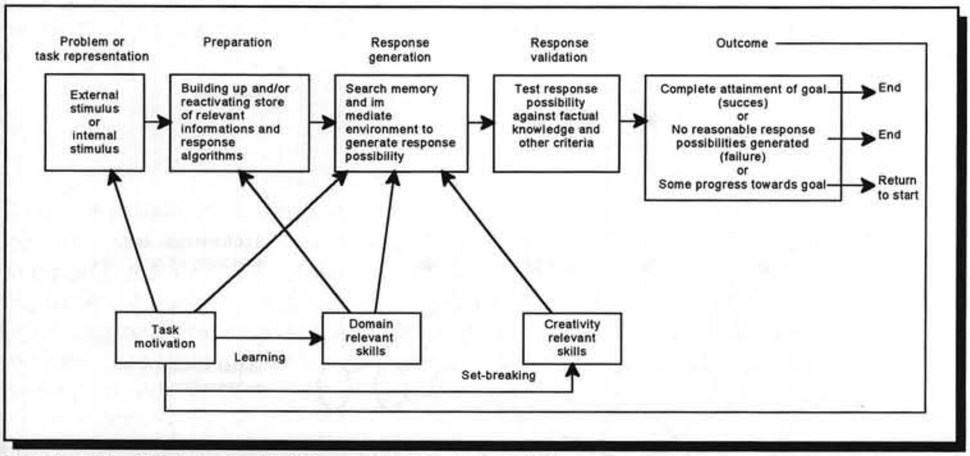


Figure 11: Componential framework of creativity

Domain-relevant skills	Creativity-relevant skills	Task motivation
Includes: - Knowledge about the domain - Technical skills required - Special domain-relevant talent **Depends on:** - Innate cognitive abilities - Innate perceptual and motor skills - Formal and informal education	**Includes:** - Appropriate cognitive style - Implicit or explicit knowledge of heuristic for generating novel ideas - Conducive work style **Depends on:** - Training - Experience in idea generation - Personality characteristics	**Includes:** - Attitude towar the task - Perception of own motivation for undertaking the task **Depends on:** - Initial level of intrisic motivation toward the task - Presence or absence of salient extrinsic constraints in the social environment - Individual ability to cognitively minimise extrinsic constraints

Table I: Components of creative performance

In order to contribute to industrial design theory and education, the design process was explored from a cognitive viewpoint, i.e. designing was defined as an information processing activity. It was questioned what role domain knowledge plays in design and what kind of expertise is decisive to performance quality. One of the most important criteria for this performance quality in design seems to be the creativity of the design. Being novel and innovative is by definition a feature of design. The research demonstrated among others, that the creativity content of the design could be measured and compared. This important finding should be applied to other domains - other than industrial design - as well.

13.3 Aircraft design

The design and construction phase of a ship can be completed within 1.5 to 2 years. The design rules and regulations allow for a very large level of experimenting within the design and construction of ships. Most of the ships are therefore one-offs and few ships are part of a standardised series. An example of standard designs offered by the bigger yards, is the Korean Hyundai. They advertise with standard designs for bulk carriers, chemical tankers, etc. Another example of standard design based on components is the Dutch Damen Shipyards. They offer owners, mostly in service vessels (tugs, workboats) a sort of Lego-components package, with which the individual wishes of owners can be catered for by combining standard components.
Yet another important advantage of ship design is the short period of pre-construction testing in a ship-laboratory and the trials after completion.
The design, construction and testing of aeroplanes has a much longer leadtime, which is five to six times longer. This is partly caused by the more rigorous testing procedures for aeroplanes in relation to ships. Although there exists a large number of aeroplane designs, the addition of new designs is relatively modest in comparison to the creation of new ship designs.

This has consequences for the design methodology used within the sector. In *"Synthesis of Subsonic Aeroplane Design"*, prof. E. Torenbeek describes the design and development of aircrafts. There are three phases within the design and development process (**Figure 12**), which are configuration development, detailed design, and service engineering.
In the *configuration phase* (or preliminary design engineering), the general layout, the external shape, dimensions and other relevant characteristics are determined. It is not intended to define the actual aeroplane configuration, such as the position of the flaps, landing gear, etc. The principal aim in this phase of design is to obtain the information required in order to decide whether the concept will be technically feasible and have satisfactory economic possibilities. **Figure 13** illustrates the different steps during this phase. An important aspect of the entire development of a new type of aircraft is that it takes place in a succession of design cycles. In the course of each of these cycles the aircraft is designed in its entirety and is researched into all main groups and airframe systems and equipment to a similar degree of detail. The extent of this detailing steadily increases as the design cycles succeed each other, until finally the entire aircraft is defined in every detail.

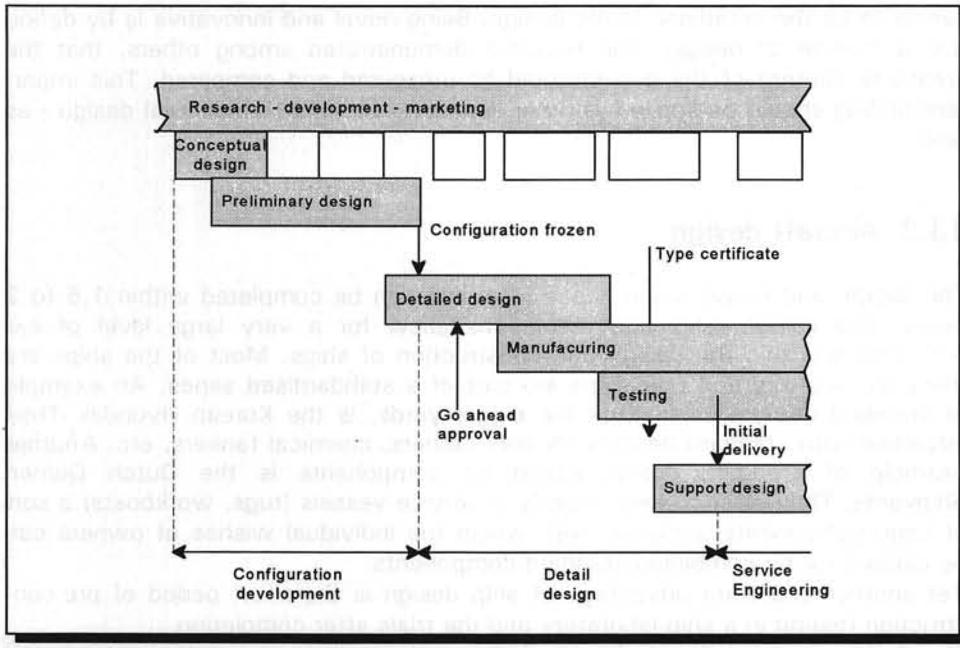


Figure 12: Phases in the design and development of aircrafts

The subsequent basic design stages are thus: conceptual design, initial baseline design, baseline configuration development, detailed design.
In the initial phase the potential demand for a new type of aircraft is further specified, through discussions with potential customers, market surveys, which leads to a clear definition of the required transport performance, such as payload, maximum range, cruising speed, climb performance, cabin arrangement, airframe services and equipment, etc. Besides, the designer will study and compare existing aircraft with competing design characteristics.
The basic feedback technical design cycle is shown in **Figure 14**. This diagram deals with technical and computational elements and could apply equally well to the design of other technical products, unlike **Figure 13**, which specifically refers to an aircraft development.

The development of a new type of aircraft is a joint effort by preliminary design engineers, aerodynamic experts, structural engineers, production and materials experts, service experts, weight engineers, engineers to design the flight control system, designers of airframe systems and (engine) equipment, and last but not least the market, financial and economic experts.
Although the future customers have an input during the conceptual phase of the aeroplane, it is up to the manufacturer to decide on the final design. Once this basic design is fixed, customers can only make cosmetic changes to the aeroplane (cabin arrangement, interior decorating, etc.).

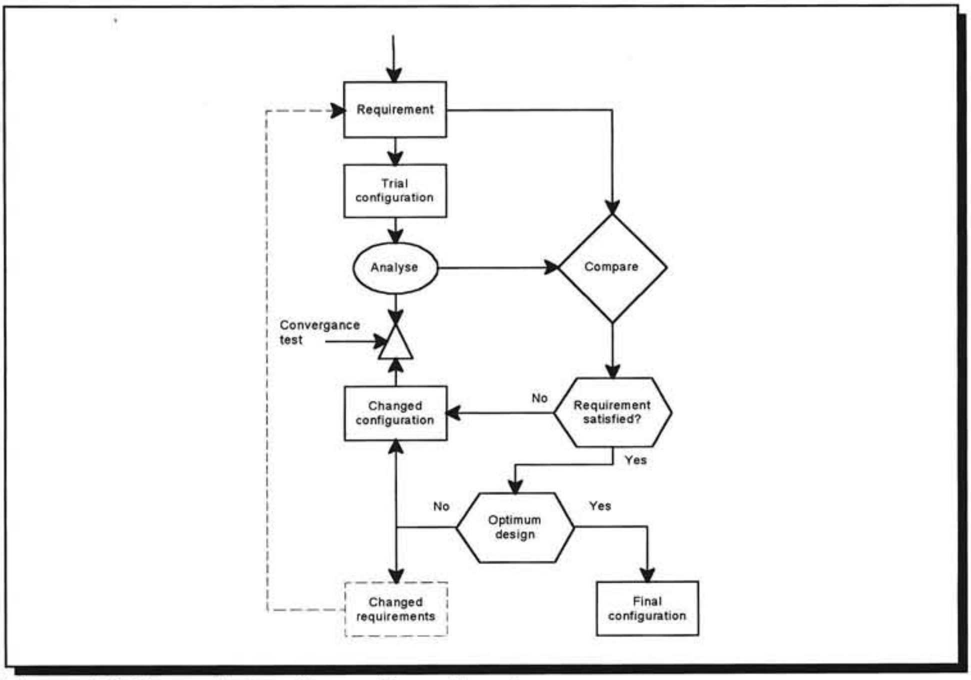


Figure 13: Steps during the configuration phase

13.4 General design methodology: creative problem solving and opportunity search

The first level of the use of creativity in the idea-generation phase of product design, will be discussed under the section of creative problem solving. The second level, the pre-product phase, is defined by Edward De Bono as the *Opportunity Search*.

The terminology used in the design process is often 'problem solving', while in fact opportunity search is meant. What is the difference? Problem solving is reactive, it means that there is something real, that has to be solved, that you can do something about. An opportunity is something you do not yet know that you want to do - and can. By training, inclination and expectancy managers in firms tend to be problem-solvers. Any deficiency in the smooth running of an organisation is a problem and it is the managers business to solve the problem and keep things running smoothly until the next problem arises.

De Bono defines three types of problems, as shown in **Figure 15**. The first type is the block-type of problem. We know the road we want to take, but there is a

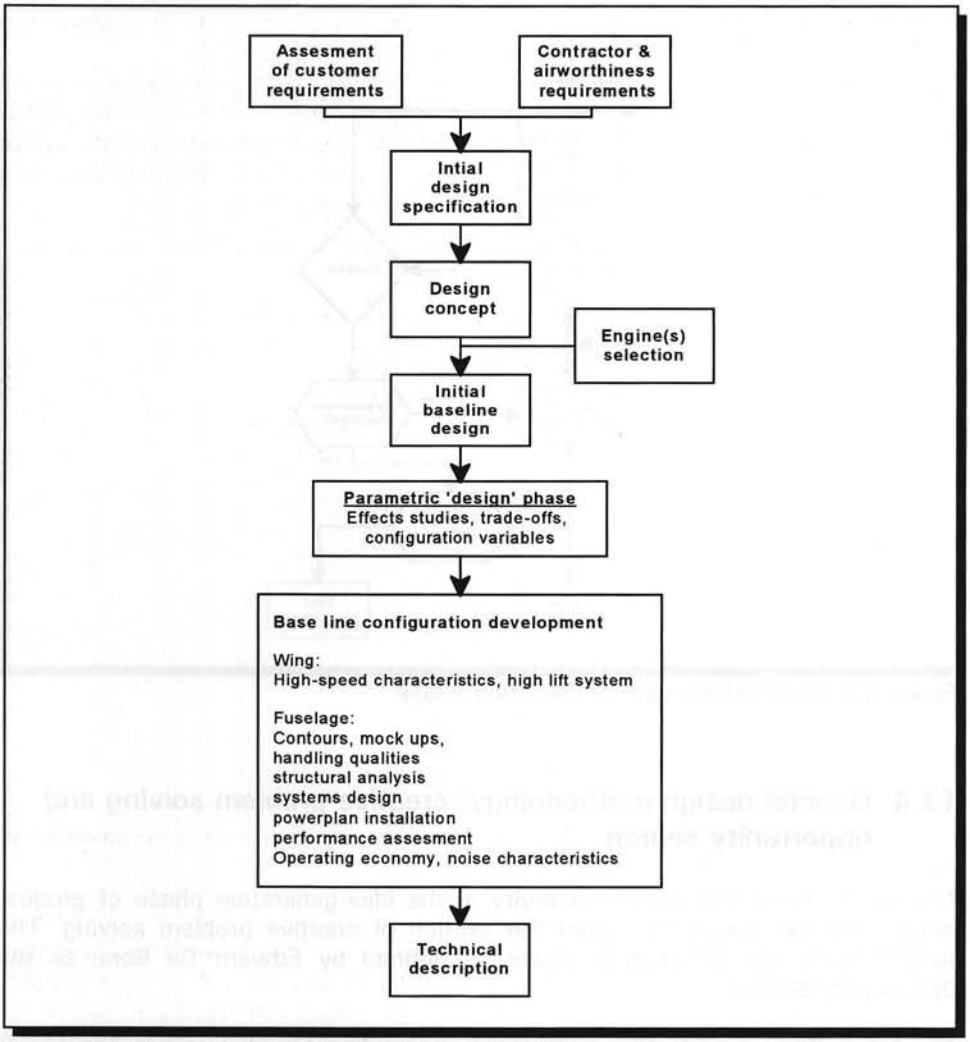


Figure 14: Basic feedback technical design cycle

block in the way. In this situation, it is easy to locate, identify and focus upon the problem. The manager then attacks the problem with his problem-solving kit and either remove the block, or find a way around it.
In the second type of problem we 'run out of the road'. In order to proceed we need more information. It may be difficult but in general this kind of problem can be solved by getting the relevant information.
The third type of problem is the most difficult to solve because it is the 'problem of no problem'. There is no block, the road is wide and open. There is nothing to

react to or focus the problem-solving skills. The manager may proceed down the road and completely miss the opportunity turning.
Managers have different styles, as already discussed in the Chapter on Innovation and the Firm. De Bono adds a number stereotypes of management styles, which he calls train-driver (operator), the doctor (problem-solver), the farmer (combination of operator, problem-solver, and opportunity searcher in a limited environment - his farm), the fisherman (opportunity searcher).

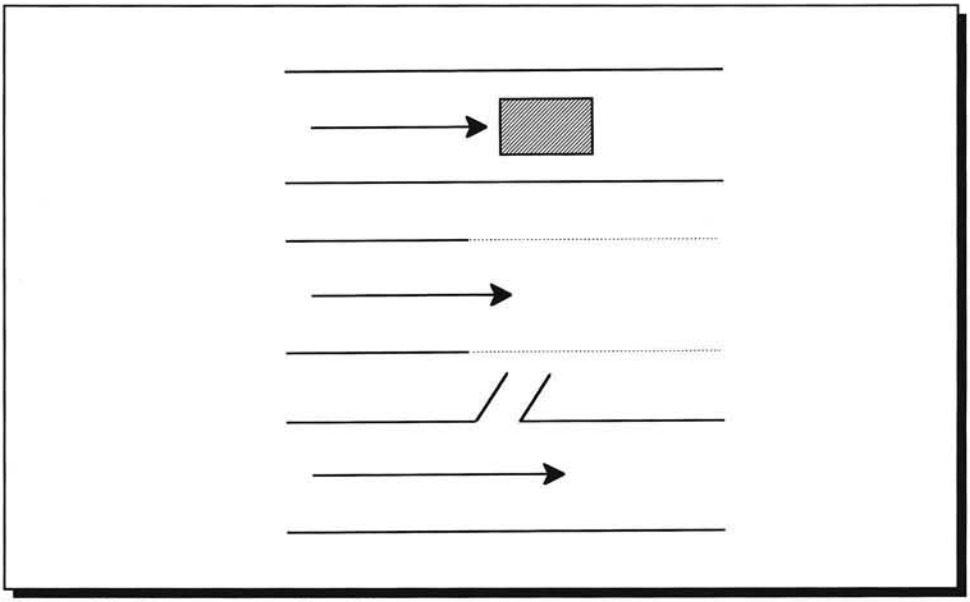


Figure 15: Three types of problems

The process of innovation in industrial design, starts often with the problem of no problem, i.e. the firm is doing well with its present product-market strategy, and there does not seem to be a reason to doubt the success of the present activities in the future. When the company is losing market share, or worse losing money with its present product line, there is a clear problem and challenge. Industrial design becomes in that situation a problem-solving exercise. But when the company is successful, what trigger should lead to an often difficult opportunity search process, where to look and what to innovate? That question is at the core of many design methodologies, but hardly ever addressed explicitly. If the organisation is managed by the stereotype managers, who De Bono calls train-drivers, than it will be evident that there is no fertile in-company basis for innovation. It requires the adventurous spirit of the fisherman to make change happen, without drama in the firm.

The concept behind opportunity search in combination with the S-curve development lead to the idea of looking for innovation triggers, as proposed in this book. The structured and scientific search for opportunities should be better incorporated in the current design methodologies. And this book is an attempt to achieve this in the field of shipping.

13.4.1 Creative Problem Solving

Engineers like formulas and therefore R. Noller proposed a function of creativity:

$$C = f_a\ (K,\ I,\ E\ )$$

This function should clarify the concept of creativity to them. Creativity is a function of an interpersonal attitude toward the beneficial and positive use of creativity in combination with three factors: ***K***nowledge, ***I***magination and ***E***valuation. This formula underscores the dynamic nature of the creativity concept; it changes through our experience. Another important element is that creativity always occurs in some context or domain of knowledge. Finally, creativity involves a dynamic balance between imagination and evaluation.
The concept of creativity can furthermore be understood by the four basic ways in which creativity reveals itself:

- Understanding the characteristics or attributes of creativity within people. This will be dealt with in **Chapter 23,** on Thinking, creativity and Innovation;
- Describing the process, operations or stages of thinking in creative people;
- Identifying the qualities of products creative people produce;
- Examining the nature of the environment, context or situation in which creative people use creativity techniques.

These four approaches to creativity are shown in **Figure 16**.

In the context of design methodologies, the emphasis is on the creative process and the creative product of that process. For many people creativity is equal to innovation. There are however important differences, as **Figure 17** shows. The remainder of this section will discuss the Creative Problem Solving (CPS) as a design methodology.

The definition of Noller of the CPS-methodology is as follows: "*By creative we mean: having an element of newness and being at least to you, the one who creates the solution. By problem we mean: any situation which represents a challenge, offers an opportunity, or is a concern to you. By solving we mean: devising ways to answer or to meet or satisfy the problem, adapting yourself to the situation or adapting the situation to yourself.*" Creative Problem Solving or CPS is a process, a method, a system for approaching a problem in an imaginative way resulting in effective action.

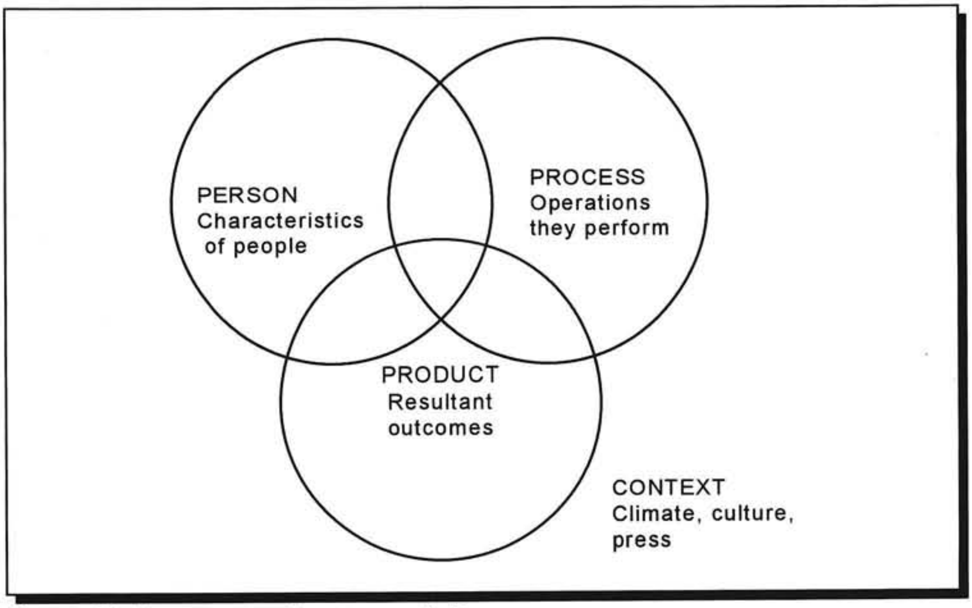


Figure 16: Four approaches to creativity

CREATIVITY	INNOVATIONS
Imagination	Implementation
Process	Product
Generating	Developing
Novelty	Usefulness
Soft	Hard

Figure 17: Distinction between creativity and innovation

CPS is a broadly applicable process that provides an organising framework for specific tools to help you design and develop new and useful outcomes. Through this system, productive thinking tools can be applied to understanding problems and opportunities; generating many, varied, and unusual ideas; and evaluating, developing and implementing potential solutions. The CPS methodology has been developed in the U.S.A., in particular in and around the Buffalo State College.

This description of the CPS-method is based on the handbook *"Creative Approaches to Problem Solving"*, by S.G. Isaksen, K.B. Dorval and D.J. Treffinger. CPS can be described at several different levels. At the most general levels, CPS is composed of three components. Components are general areas or categories of activity people deal with when they are solving problems or opportunities creatively. The three components are: Understanding the Problem, Generating Ideas, and Planning for Action. Within each component there are specific stages, which is a smaller, more specific level of operation within CPS. CPS distinguishes six specific stages within the three components. The stages within Understanding the Problem are: Mess-finding, Data-finding and Problem-finding. The stage within Generating Ideas is Idea-finding. The Planning for Action component includes: Solution-Finding and Acceptance-finding. **Figure 18** illustrates the Creative Problem Solving methodology.

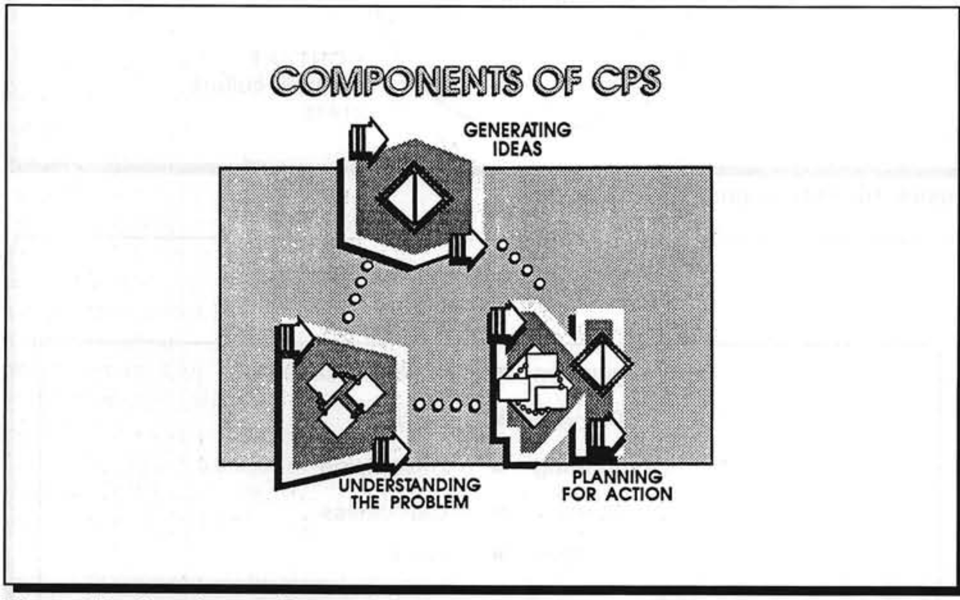


Figure 18: Creative problem solving

At the next and more specific level, each CPS stage has two phases. Together, these phases emphasize the dynamic balance between divergent and convergent thinking. The first phase is divergent thinking in which you come up with or generate many, varied and unusual options. The second phase is convergent thinking in which you analyse, develop or refine the options you generated.

Finally, the most basic level of the CPS framework involves specific tools or techniques. These techniques help to purposefully change the perception of the reality in order to create new insights, and these techniques usually have either a divergent or convergent emphasis. These techniques will be described in **Chapter 24**.

Apart from the methodology, the CPS approach provides the users a common language for an effective problem-solving framework. The three components and the six stages will be briefly discussed.

Component; Understanding the Problem

The three stages within this component are Mess-finding, Data-finding and Problem-finding. *Mess-finding* deals with the question, "*What is the challenge, opportunity or concern on which we are going to be working?*" The word 'mess' means that at this stage the situation is fuzzy, broad, general and ill-defined. *Data-finding* focuses on seeking as much and as varied information that may help you state your problem. *Problem-finding* is the stage in which you develop workable, stimulating and specific problem statements. This is the most crucial part in the CPS method, as the definition of the problem/opportunity determines to a large extent the contents of the following stages.

The ambiguity during this phase and foremost the importance of looking at the problem in different ways (different conceptual/mental models) can be illustrated with a simple example, taken from a book on problem definition by D. Gause and J. Weinberg, *"Are your lights on?"* **Figure 19** shows an office building where the users complain about the long waiting time before the lifts. Ask an audience of engineering students to propose solutions for this problem, and they invariably come up with technical/operational solutions like: increase the speed of the lift, put in an extra lift, or change the working hours (more flexible). The latter solution already points at a whole new category of solutions, which are organisational and less costly. Some solutions are extravagant, such as "*burn down the building and cash in on the insurance premiums and relocate the office*", but what we are after is the student who asks the simple question "*how is the perception of waiting for a lift and how is it actually measured?*" This brings us to solutions like manipulating the waiting experience, for example by equipping the front of the lift with floor-numbers, so people know how long it will take before the lift arrives, or putting a mirror next to the lift, or a billboard with company information, or a television.
The creative person does not have to be so fluent in the Idea-generation phase, but especially in the Problem-definition phase. Great thinkers and scientist have always find a new way of looking at the reality. Changing the perception of the problem is crucial.
Keep simply in mind that the reality is there and real, and it is up to us to uncover it, like the alternative definition of the sculptor as somebody who takes away the superfluous pieces of material, as the statue is already in the stone.

In the maritime sector a good, or may be bad example of a problem statement is at the basis of the U.S. Oil Pollution Act 1990. Apart from many noteworthy procedures for increasing the operational safety of ships, in particular oil tankers in American waters, the OPA-regulation prescribes that the oil tankers calling at U.S. ports should in the future be based on a double-hull design.

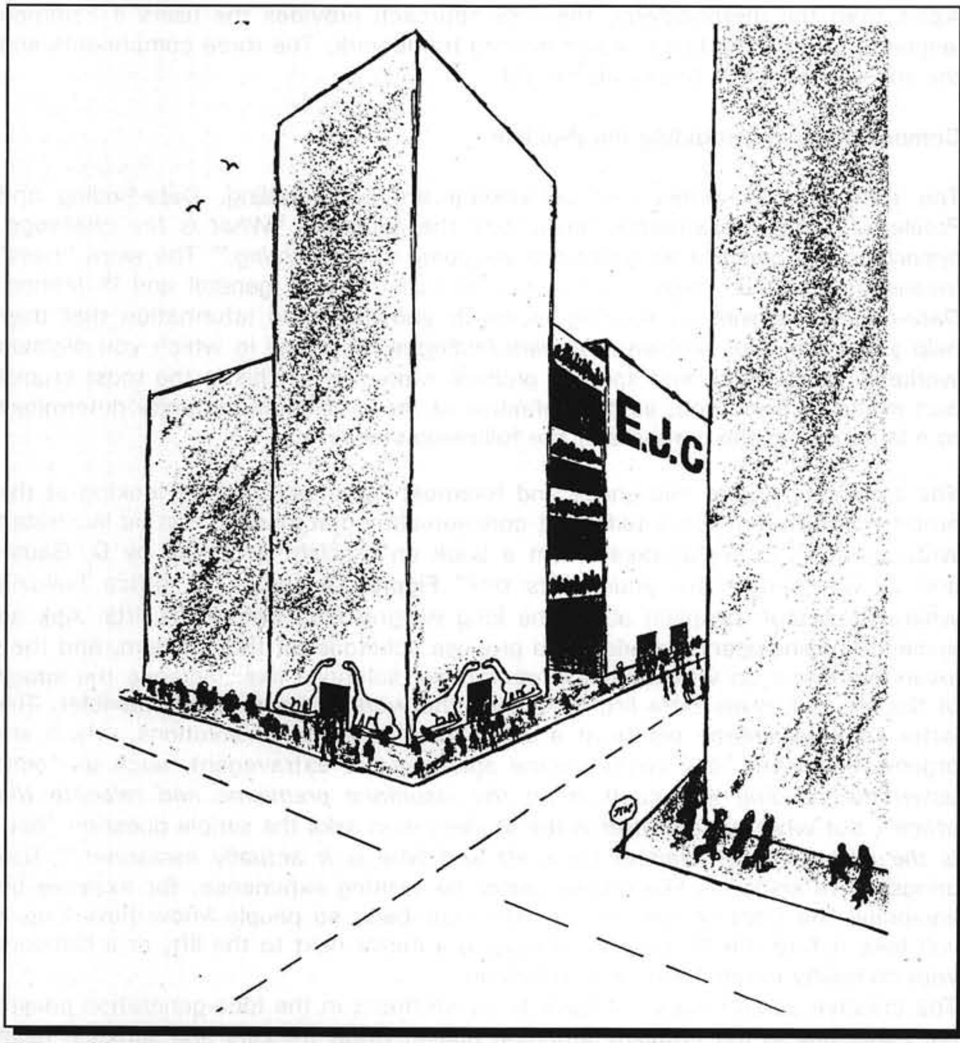


Figure 19

Although 75 percent of all maritime accidents are caused by human failure, the focus has simply been on design technology. The comparison with the previous lift-example is evident. If the lawmaker had defined the accident/pollution problem in a different way, focused on avoiding human failures, than the outcome would have been completely different, and possibly less costly and more effective. The important Exxon Valdez spill was caused by a human failure, and caused a spill in spite of the double bottom of the oil tanker.

Component: Generating Ideas

Idea-finding takes the various problem statements as a starting point and uses creativity techniques to create new insights, either direct or in stages. Often indirect analogies based on classes of ideas may trigger new ideas; this phase is a merry-go-round and mostly associated by people as the creative phase. Again, problem definition needs even more creativity than this idea-finding phase.

Component: Planning for Action

The two stages within this component are Solution-finding and Acceptance-finding. *Solution-finding* involves working on promising ideas to analyse, refine and improve them. *Acceptance-finding* challenges you to look at the solutions/options through the eyes of others and to examine your potential solutions in ways that will lead to effective action, while counteracting potential or actual objections or resistance. This part of the CPS methodology is very much part of Innovation Management, as discussed before.

Variations on the CPS-theme

The CPS methodology has been developed shortly after Guilford's address before the American Psychological Association in 1950, by Alex Osborn and published in his book *"Applied Imagination"* (1953). He described a seven stage version of CPS, which is summarised in **Figure 20**, that condensed in 1963 in a three stage approach as shown by **Figure 21**.
Sidney Parnes modified Osborn's approach into a five stage model (**Figure 22**), which he later on presented in a more visually attractive style, which became a trend in CPS since then (**Figure 23**).
Later on Parnes, Noller and Biondi modified again the CPS five stage model which was used for a long time. Many individuals and companies (managers) participated in CPS-workshops and I myself had the opportunity to work with Parnes and Biondi during such a CPS workshop.
In 1985 Isaksen & Treffinger modified the approach as shown by **Figure 24**, which was consequently restructured in the three component, six stages approach as shown in **Figure 25**.

OSBORN'S SEVEN-STAGE CPS PROCESS		
1	Orientation	Pointing up the problem
2.	Preparation	Gathering pertinent data
3	Analysis	Breaking down the relevant material
4	Hypothesis	Piling up alternatives by way of ideas
5	Incubation	Letting up to invite illumination
6	Synthesis	Putting together the pieces
7	Verification	Judging the resultant ideas

Figure 20: Osborn's 1953 seven-stage version of CPS

OSBORN'S THREE-STAGE CPS PROCESS	
1	Fact-finding: problem definition (picking out and painting up the problem and preparation (gathering and analysing the pertinent data)
2	Idea-finding: Idea production (thinking up tentative ideas) and idea development (selecting, reprocessing, modifying, and combining)
3	Solution-finding: Evaluation (verifying tentative solutions) and adoption (deciding on and implementing the final solution

Figure 21: Osborn's 1963, three-stage version of CPS

PARNES' FIVE-STAGE CPS PROCESS

Fact-finding: Discovering relevant facts

Problem-finding: Determining the real problem

Idea-finding: Generating options

Solution-finding: Evaluating ideas with criteria

Acceptance finding: Preparing to put an idea into effect

Figure 22: Parnes' 1967, five-stage version of CPS

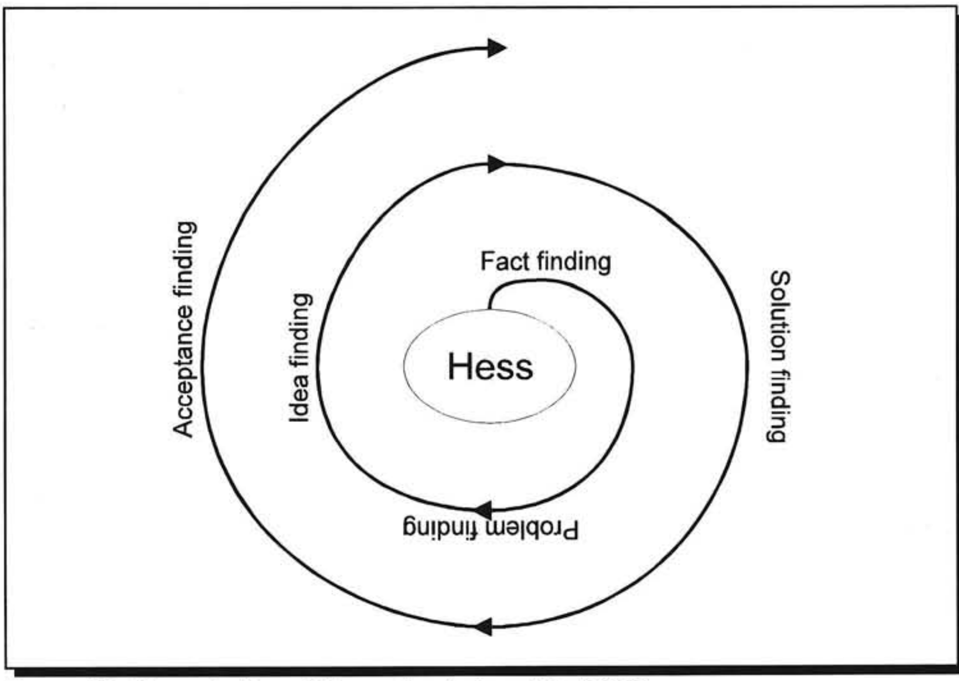


Figure 23: Presentation of Parnes' spiral model of CPS

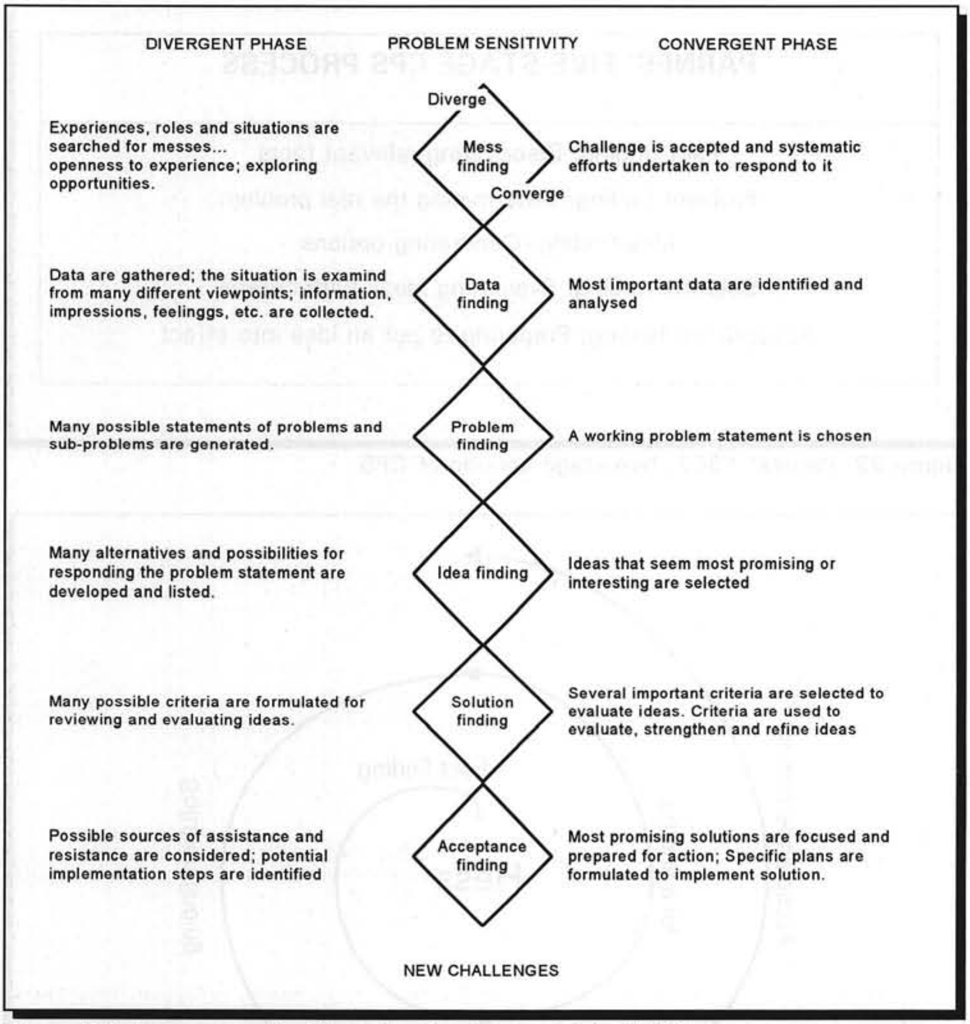


Figure 24: Isaksen an Treffinger's six-stage model of CPS

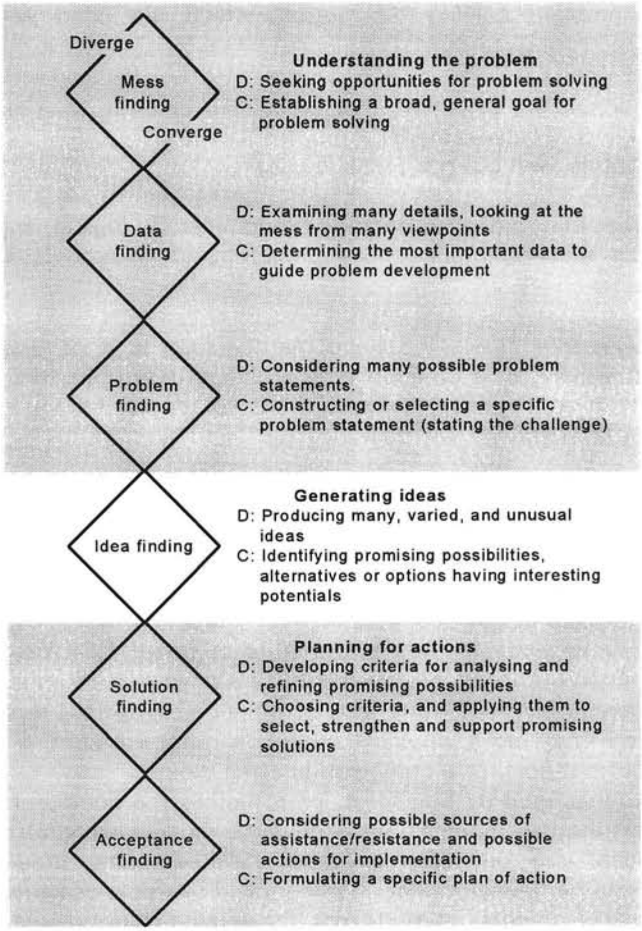


Figure 25: Isaksen and Treffinger 1987 model of CPS

Vincent Nolan's *"The Innovators's Handbook"* distinguishes two broad categories of problem solving techniques, which are used within the CPS framework:

- Those suitable for problems that lie within, or close to, present levels of knowledge and achievement;
- Those that lie well outside those levels.

Problems of the first category require predominantly logical analytical skills; problems of the second nature require predominantly inventive, intuitive, creative skills.

In short, the Creative Problem Solving methodology is a general approach to structuring and solving in a creative way problems and opportunities; it can be used effectively in an engineering environment, as the case-study on *"Innovation in Forest products Shipping"* will demonstrate.

13.5 System Dynamics

In *"Introduction to Computer Simulation: The System Dynamics Approach"*, by N. Roberts et al, the origin and meaning of simulation modelling is explained. Originally, the word *simulate* meant to imitate or feign. This meaning suggests one important characteristics of simulation: to simulate is to imitate something. Simulation generally involves some kind of model or simplified representation. A simulation model may be a physical model, a mental model, a mathematical model, a computer model, or a combination of all these.
Most of the models used by engineers, were before the computer age, physical models or mathematical models. Since physical models are often relatively expensive to build and unwieldy to move, mathematical models are often preferred. In a mathematical model, mathematical symbols or equations are used instead of physical objects, to represent the relationships in the system. With the decline in the cost of computer calculations, the use of simulation models, based on mathematical relationships has really taken off.
The use of simulation models implies a paradigm that is called the *systems approach*. There are many systems approaches; the one presented in this section is particularly suited for dynamic feedback systems, which are initially not well defined and new. It is not only a tool for simulation, but more importantly a tool for the conceptualisation of (new) variables and parameters and their relationships within a system. This requires the definition of boundaries, limits and the time-dependent behaviour.
The origins of system engineering can be traced to the engineers working in the 1930s on flight control, fire control and various other systems, which are based on servomechanisms (like the thermostat, and what is now called feedback systems). One of those engineers just after WW2 was Jay Forrester at MIT,

who developed the technical systems engineering methodology into an industrial application (logistics), which was first published as *"Industrial Dynamics"* (1961). On the basis of this design methodology, the well-known book Limits to Growth from the Club of Rome was written (World Dynamics). The merits of the approach used in these studies as a powerful conceptual tool was recognised by a growing number of academics and they set themselves apart from other system engineers by calling the methodology System Dynamics.

The design methodology of systems and their simulation, is schematically shown in **Figure 26**. The typical sequence of activities within the process is:

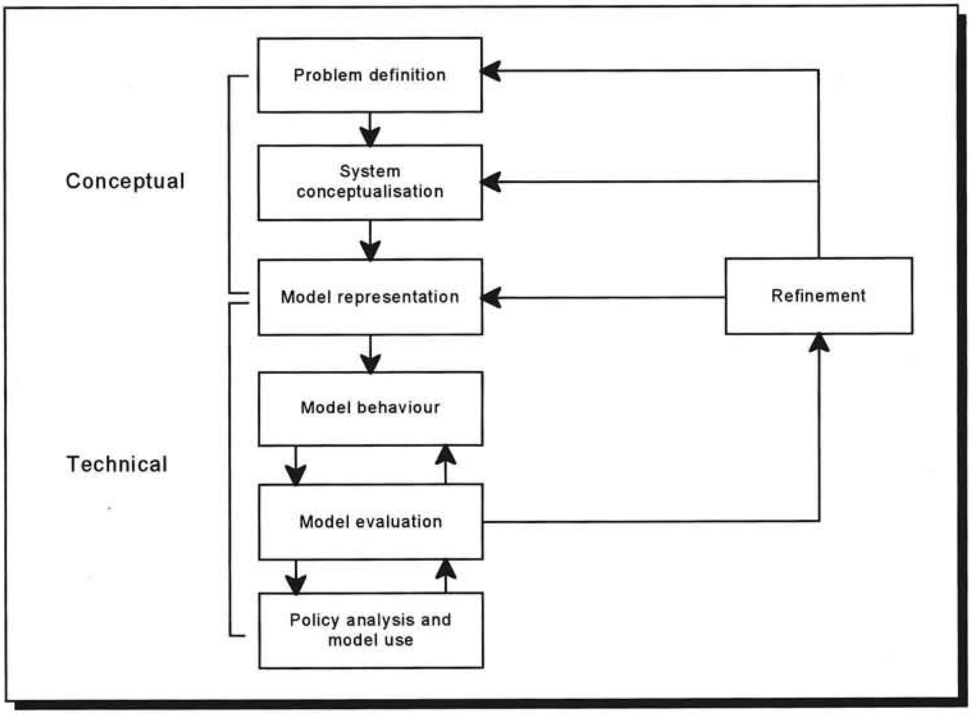


Figure 26: Phases in the model-building process

- *Problem definition*: definition of a problem to study and that is amenable to analysis in systems terms. Important properties of dynamic problems are that they contain quantities that vary over time, that the forces producing this variability can be described causally, and that important causal influences can be contained within a closed system of feedback loops. The causality of the system is not always present; in those cases, more probabilistic techniques like Monte Carlo simulation are more appropriate.

- *System conceptualisation*: The second phase in the model-building process involves committing to paper the important influences believed to be operating within a system. Systems may be represented on paper in several fashions, the three most common being causal-loop diagrams, plots of variables against time, and computer flow diagrams.
- *Model representation*: In the third phase of the model-building process, models are represented in the form of computer code that can be fed into the computer. System dynamics uses the simulation language Dynamo, of which a powerful variation, is available under Windows.
- *Model behaviour*: In this phase, computer simulation is used to determine how all of the variables within the system behave over time.
- *Model evaluation*: In the fifth phase, numerous tests must be performed on the model to evaluate its quality and validity. These tests range from checking for logical consistency, to matching model output against observed data collected over time, to more formal statistical tests of the parameters used within the simulation.
- *Policy analysis and model use*: In the last phase, the model is used to test alternative policies that might be implemented in the system under study. This is an important aspect of system dynamics modelling, as it stimulates the designers to look beyond the model boundaries for new solutions. Because, often, the solution cannot be found by applying current policies.

The whole process is of course a continuous iteration, which gradually converge (hopefully!) to a solution.

Causation, feedback and system boundary

Causal thinking is the key to organising ideas in the system dynamics approach. Typically a designer identifies key causal factors and diagrams the system of causal relationships before proceeding to build a computer simulation model.
The causal relationship of Newton's pushing force on an object can be represented as shown below, where the arrow between the two phrases can be read as *causes*.

PUSHING FORCE -------------------> ACCELERATING MOTION

While thinking in terms of causal relationships is necessary to cast a problem in a form that can be analysed using system dynamics, it is not sufficient. Causal chains can often be linked together nearly endlessly to create an undisciplined morass of causal relationships. One way to clarify the representation of a system is to focus on circular chains or causal *loops*. Within a causal loop, an initial cause ripples through the entire chain of causes and effects until the initial cause eventually becomes an indirect effect of itself. This process is called *feedback*. **Figure 27** illustrates the representation of causal loops or feedbacks with the system of the room thermostat.

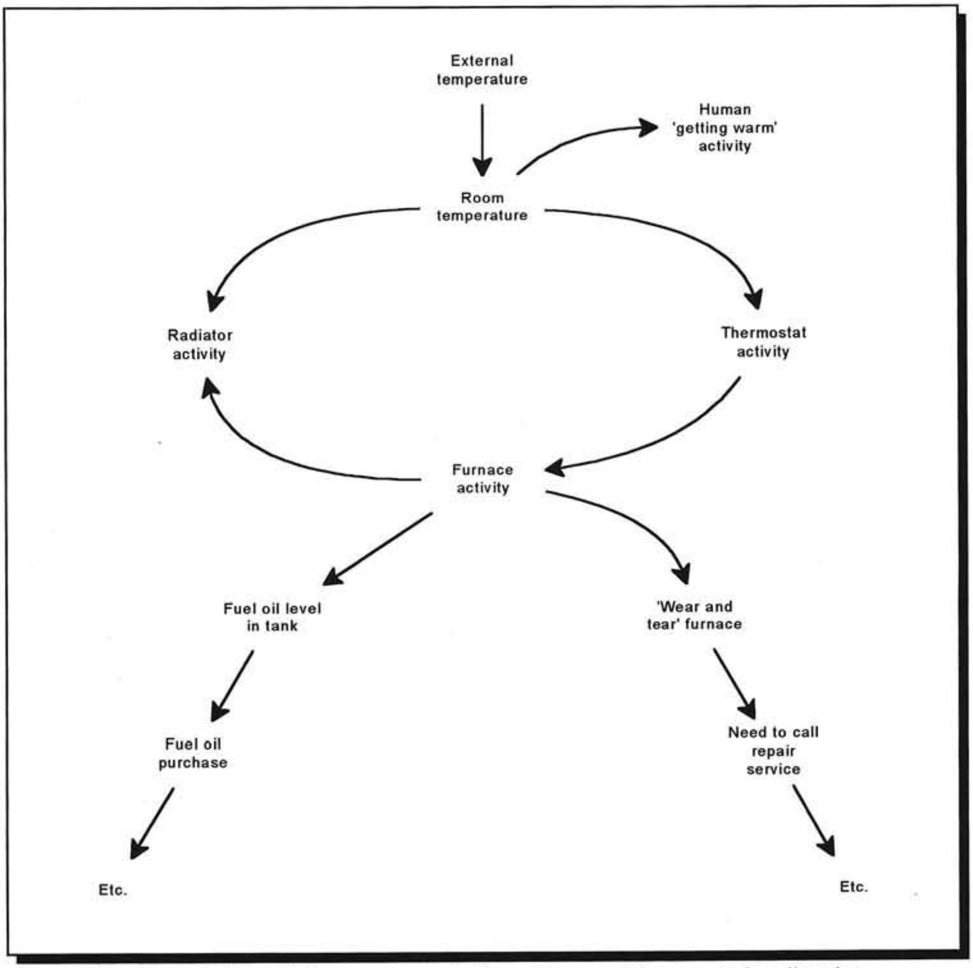


Figure 27: Illustration of the representation of causal loops or feedbacks

Feedback-oriented thinking helps to indicate how relationships are to be represented in a system model. But further attention is needed to specify the boundary for a system model. Simply put, a *system's boundary* is a line of demarcation that determines what is included in the system and what not. Identifying a system's boundary is a complex process of defining the size, scope and character of the problem being studied.

These are the basic ingredients of the system dynamics design methodology. Many books and papers are written with applications in almost every domain. An example, taken from Coyle's book *"Management System Dynamics"* (1977) on the design of an oil tanker shipping system will clarify some of the concepts.

It should be noted that the model dates from almost twenty years back; much more complicated oil tanker models have been developed since, but the purpose is to illustrate the approach, see **Chapter 19**.
The methodology is a very efficient way to let the student understand the dynamic behavior of a system, and empower them to try to model new and unfamiliar systems, by using their brain first instead of copying work of others.

13.6 Structured Analysis

A design methodology which can be used on an operations-oriented domain, is the function-modelling technique *Structured Analysis*. This approach is developed by Ross, Schoman, Bravoco, Feldman and Softec in the early 1970s for the US Air force, and it is also known under its trade name IDEF, which stands for (***I***ntegrated computer-aided manufacturing ***DEF***inition method). IEDF has three components:

- IDEF0 - A functional model methodology whereby the functions of a complex manufacturing environment are graphically represented in such a way as to show the structural relationships between them;
- IDEF1 - An information model methodology whereby the information needed by an entity to perform its function is graphically represented;
- IDEF2 - A dynamics model methodology whereby the time varying behaviour of the function and information are described graphically for a manufacturing system.

The IDEF0 methodology, focuses the attention on activity-clusters, in coherence with their operation-factors. It is based on a simple hierarchical diagram-language, which is just powerful enough to model a basic activity structure. The central modelling element is called the Activity/Factor diagram, or A/F-diagram for short. An A/F/ diagram is composed of activity-clusters and four types of factor-relationships: inputs, directives, outputs and action-resources. As shown in **Figure 28**, activity-clusters are represented by action-boxes, with a verb as a title. Action-boxes on the same diagram are supposed to be disjunct. Factor-relationships are represented by factor-arrows; a noun may be attached as title.

Inputs are understood as subjects of the activities; they are indicated by entering arrows at the left side of an action-box. Directives are understood as operational environments of the activities; one may think of instructions, parameters, or signals of exceptional situations. Directives are represented by entering arrows at the top of the boxes. Outputs are taken as results of the activities represented by the action-boxes; they are shown as outgoing arrows at the right side of an action-box.
An output may serve as input, directive or activity resource for the other activities. Activity resources (or executors) are conceived as actors in the form of

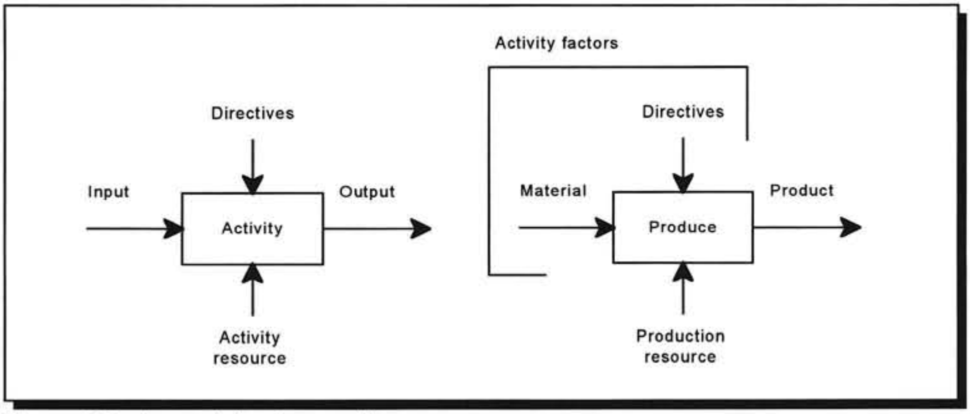


Figure 28: An activity factor diagram

persons, teams, units in an organisation, protocols or machines, which (partly) execute the activities in question. They are represented by arrows at the bottom side of an action-box.
Factor-relationships may refer to a flow or a precedence condition, but they also may have another meaning. Because inputs and directives enter action-boxes from the left and top respectively, and because outputs are leaving at the right side, the natural ordering of boxes, to indicate dependence of activities, is from the top-left corner to the bottom-right corner. The second essential element in A/F-modelling is the diagram hierarchy depicted in **Figure 29**.

Logistic engineering

The Structured Analysis methodology is particularly suited for an operational application, such as in logistic engineering. In the development of logistic systems, four main phases can be distinguished, which lead to the following results: the reference scheme, the conceptual model, the process model and the final design. The corresponding design tasks are shown in **Figure 30** (based on prof. dr ir J.J.M. Evers).

The activities corresponding to the task 'formulate design objectives' should give rise to a clear understanding of the problem area, resulting in the formulation of functions which have to be realised by the design and the corresponding assessable design objectives.
The activities under the heading 'make conceptual model' should result in three products which can be assessed separately: the function model, the information model and the operational model.
The function model contains the delimination model, differentiation and segmentation of the desired functions. Communication with the field of application and agreement with the client are essential elements of this phase.

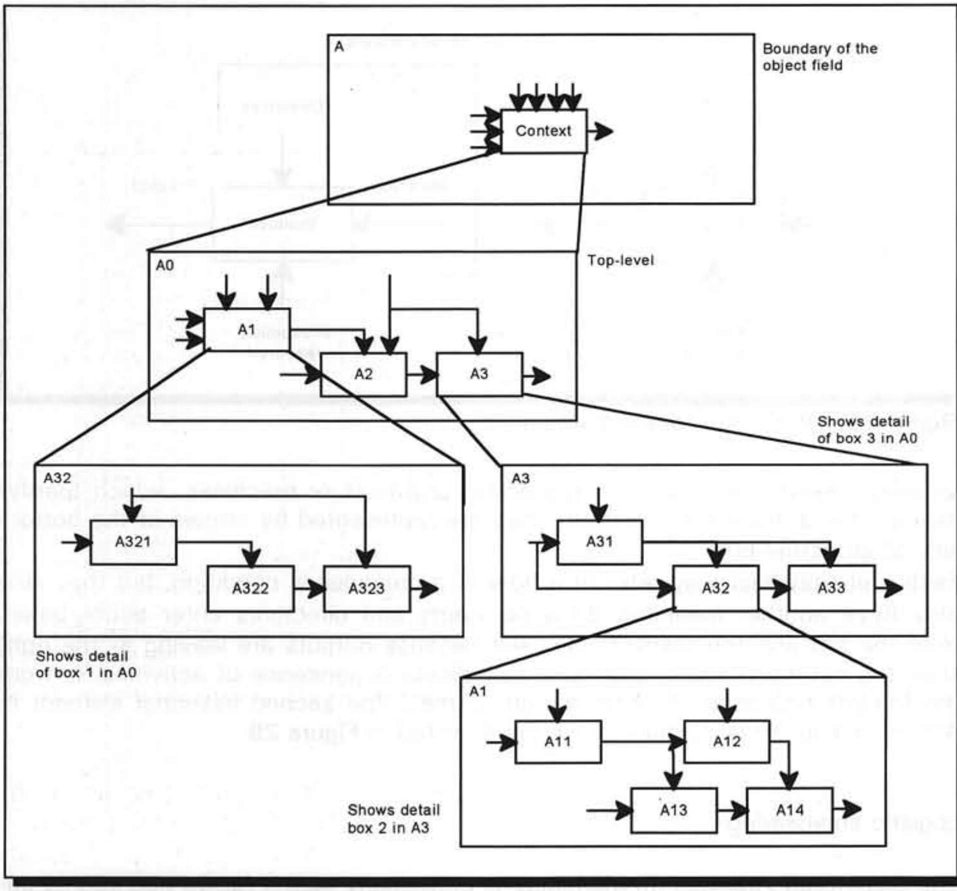


Figure 29: Model hierarchy

Information modelling is concerned with the area of application of the system to be designed, the recording of events, the control/management information and the data logical relation of this information. The operational model involves the working of the sub-processes which support the separate functions, together with the information model and the system environmental interface, to which the user/system-interface also belongs.

The process modelling, confronted with the technical possibilities, leads to further formalisation of the operational model, resulting in a formal description of the design. In principle one can now evaluate the working of the design with the aid of simulation. Simulation is an essential tool for the development of logistic systems. On the basis of the conceptual model and the process model a provisional estimate and a provisional implementation plan can be drawn up and a start can be made on the actual design.

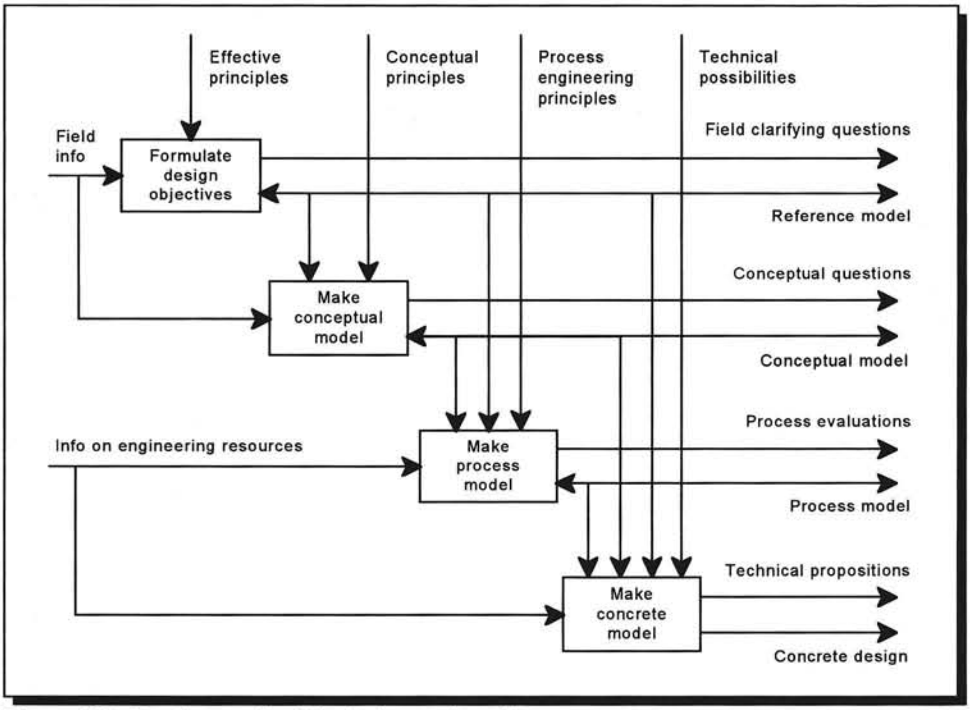


Figure 30: Design task of logistic engineering

In recent decades much effort has gone into achieving computer support for the design process of complex management systems. Designing, then, is taken to be a phased, yet completely integrated, process of increasing specification, resulting in simulation models by which, with the aid of the computer, direct validation experiments and performance analyses can be carried out.
One of the missing elements in relation to this methodology is a generic system to describe the functions, the interaction, the area of application and the control of logistic equipment. Furthermore, it will be necessary to integrate the physical and management functionality further.

The structured analysis methodology will be illustrated with the help of a case-study on the design of an operational decision support system of the stowage of products on chemical tankers in **Chapter 22**.

The IDEF0 design tool is very useful, as will be demonstrated by this case-study, but it lacks the explicit use of creativity techniques as part of the design process. Implicitly, this depends on the quality of the designer. The following design methodology that will be discussed, *system dynamics*, will stimulate the designer to more intellectual freedom and the use of creativity in the design process.

13.7 Benchmarking

Benchmarking is not a design methodology by itself, but is a means to create a starting point for the design process. As it is a very important technique, it will be discussed in this chapter.
The benchmarking examples, discussed in **Chapter 8**, show the process of defining industry performance indicators and comparisons within the Panamax bulk carrier and container ship segments of the maritime markets. The macro or sector approach to benchmarking, is useful in order to get a feel for the competitive factors and advantages to be created or not in these segments.
A benchmarking project is usually executed at the (micro) company level, and not at the macro level of the entire segment. Before the benchmarking methodology is further discussed, two examples from the chemical tanker industry will illustrate the process. The first example concerns the largest operator of parcel tankers in the world, Stolt-Nielsen, which is quoted on the New York Stock Exchange. In their company magazine Stolten (April 1995), the president S. Cooperman says the following:

The analysts and investors that follow our company want an easy to understand statistic to help them understand our performance, and we very much want to oblige. In July 1993, we developed freight, utilisation and revenue indexes to measure global trends in our business. Since utilisation and freight rates determine the revenue earned, these two components were selected together with revenue.
The indexes, like any simple tool attempting to describe a complex process, have to be used with caution. The parcel tanker trade is composed of many trade routes each with its own freight and utilisation trends. The indexes reflect global trends as long as no major structural changes occur.
The indexes presented below are *revenue*, and the *sailed in time charter* (**Table II**). This latter index reports fleet revenue less voyage costs (commissions, port expenses and bunkers) per operating day. It correlates well with the revenue index over the long term but there some significant differences in some quarters.

The second example is taken from Jo Tankers, another large chemical tanker company. In the April/May 1995 issue of their company magazine *"JO Journal"* they publish the performance ranking of their 21 owned chemical parcel tankers. The performance of each ship is measured on the basis of ten indicators: safety, environment, operational performance, cargo contamination, operational expenditures, administrative, cleaning en general expenditures, off-hire, quality management standards, hull & machinery statistics and age. These factors have different weightings, ranging from 1 to 3, while the total maximum score is 20. They also relate the current performance to the past performance of the ship as a whole. **Figure 31** shows a part of the performance ranking of the JO fleet.

Year		1990	1991	1992	1993	1994
Revenue index	1	1.00	1.26	1.12	1.00	1.10
(per quarter)	2	1.11	1.22	1.10	1.01	1.12
	3	1.10	1.13	1.15	1.01	1.13
	4	1.12	1.16	1.06	1.07	1.17
Sailed in T/C hire index	1	1.00	1.21	1.05	0.93	1.11
(per quarter)	2	1.03	1.23	1.07	0.94	1.13
	3	1.04	1.14	1.10	0.96	1.14
	4	1.21	1.24	1.01	1.06	1.16

Table II: Sailed in Time charter hire and revenue indexes

This is a unique example of internal benchmarking, which provides an objective basis for internal comparisons and feedback to crews. It illustrates again that performance of ships can be measured in spite of the fact that many variables are 'soft'. At the same time, these performance indicators may provide a platform for the definition of future outline specifications. Therefore it is necessary to get a better insight in the underlying reasons behind the performance. What are the causes and processes that lead to a certain outcome and performance. For example if chemical tankers score continuously low on the item 'cargo contamination', then it may be worthwhile to investigate the causes. This may be for example a contamination as a result of cracking in the tanks, which caused a leak. This is completely beyond the control of the crew, but may be a good trigger to revise the conceptual and structural design of the ship. It may lead for example to the design of the cylinder tanker as discussed in one of the case studies.
Benchmarking, either external - in comparison to the competitors - or internal - in comparison to the other ships in the fleet - is a power tool to establish triggers for design and operational innovation.

The Benchmarking methodology starts out with the question: what do we have to measure? If the firm wishes to innovate its products or services, then it should concentrate on the critical success factors, which are the critical few factors that have the most impact across the entire business system. Defining these factors and next measuring them, provides the management and designers with valuable knowledge and insight in the basic triggers for innovation.
The benchmarking methodology is thus a stepping stone for innovation in design, to create a meaningful starting point, not random - as for example by using brainstorming techniques - but in a structured way. Not enclosed within the company environment, but performance of the company relative to the competition.

	Safety	Environ-ment	perfor-mance	Cargo conta-mination	Opex budget	Adm, clean & gen. app	Off-hire
Weight	3	3	3	3	2	1	1
Vessels							
JO Palm	4	4	5	5	4	4	4
JO Maple	4	5	4	5	4	4	3
P.Gallant	3	5	4	5	4	4	5
JO Cedar	4	5	3	5	4	5	4
JO Hegg	4	3	4	4	5	4	4
JO Ebony	3	3	3	5	5	5	5
JO Spruce	3	5	3	3	4	5	5
Jo Alder	5	2	3	5	3	4	4
Jo Oak	4	3	4	2	5	3	3
Jo Gran	2	4	4	4	4	3	4

	QMS stand	H&M statis-tics	Age	Total	Rating (%)	Earlier years 1993	1992
Weight	2	1	1	20	5 = 100%		
Vessels							
JO Palm	4	5	3	4.300	86	2	3
JO Maple	4	5	3	4.250	85	9	5
P.Gallant	3	5	5	4.200	84	17	13
JO Cedar	4	5	1	4.100	82	-	-
JO Hegg	4	5	5	4.050	81	4	10
JO Ebony	3	5	5	3.900	78	12	4
JO Spruce	4	5	1	3.700	74	13	-
Jo Alder	4	5	2	3.700	74	3	-
Jo Oak	4	5	5	3.650	73	14	11
Jo Gran	4	5	5	3.550	71	-	12

Table III: Ranking of the Jo Tanker fleet

Benchmarking is used in the initial phase of the design methodology, at the start of the preliminary design. But also later on, once the product or service is conceived and in operation, the process of benchmarking continues, in order to be alert for diminishing returns of performance. In fact, benchmarking is the basic tool for assessing a company's products S-curves. Benchmarking is in principal relative performance, relative to competition, while S-curve performance is absolute performance.

Watson gives the following operational definition of benchmarking. An operational definition is one that describes the critical success factor(s) - in terms of observable characteristics or measurements - of the process, product or service being defined. It begins with the definition of the *benchmark goal statement*, which should be translated into operative terms. This requires answers to the following questions:

- What measures will give the management (designers) the best picture of reality in terms of what we want to know?
- Do we have the information or data needed for these measures?
- Is the information available in a measure that will meet our needs?
- Is the measure common enough among industry or business representatives that comparable measures can be found?
- Can these measures be charted for making comparisons?
- How likely is it that another company will have comparable data?
- How likely is it that another company will give us this information?
- Would we give it to another company that may or not be a competitor?

Figure 31 illustrates the Benchmarking process model, which consists of four steps:

1. Planning the benchmarking project;
2. Collecting the necessary data;
3. Analysing the data for performance gaps and enablers (=practices that lead to exceptional performance);
4. Improving by adapting process enablers.

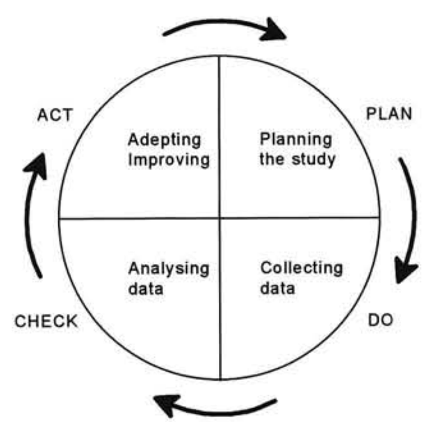


Figure 31: The benchmarking process model

The first step, planning the project, is schematically shown in **Figure 32**. There are three phases to the planning step:

- The company must identify its strategic intent, core competences, capability maps, key business processes and critical success factors;
- The particular process to be benchmarked must be documented and characterised, to determine its inherent capability;
- Requirements must be established for selecting benchmarking partners, given the benchmarking objective.

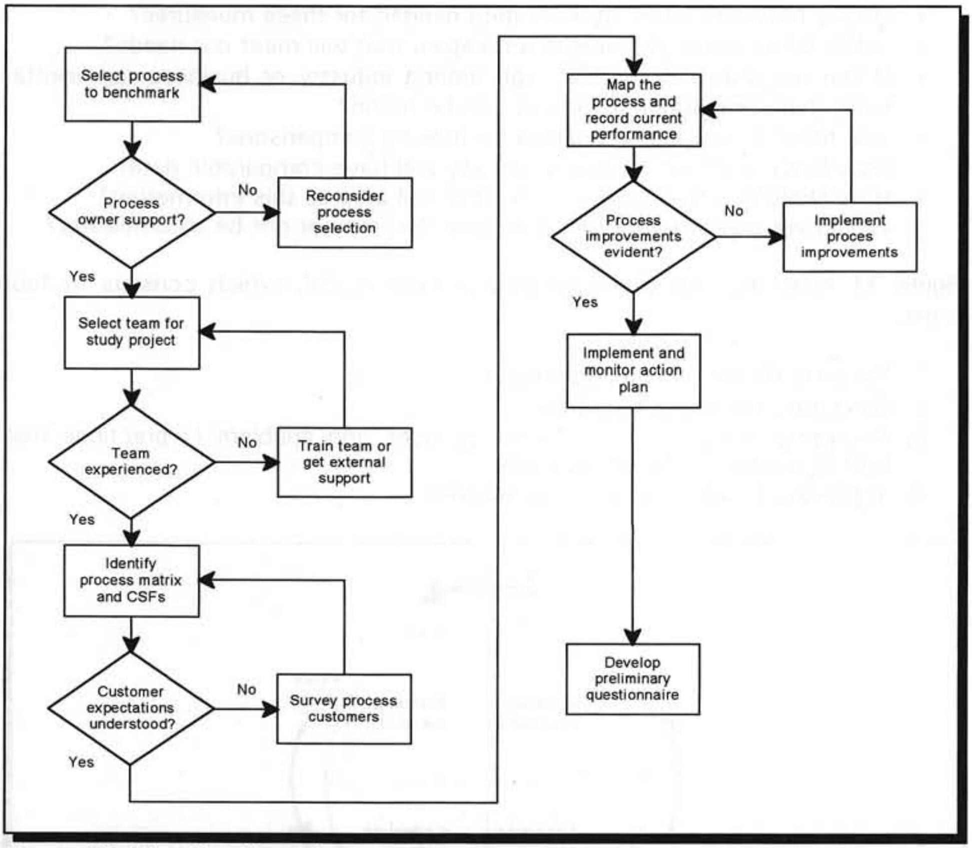


Figure 32: Planning flow diagram

The second step, collecting the necessary data, is schematically shown in **Figure 33**. This step contains three phases: internal data collection, secondary research, and external primary research/data collection.

The third step, analysing the data for performance gaps and enablers, is schematically shown in **Figure 34**. The five phases that characterise this step are: data analysis, data presentation, root-cause analysis, results projection and enabler identification.

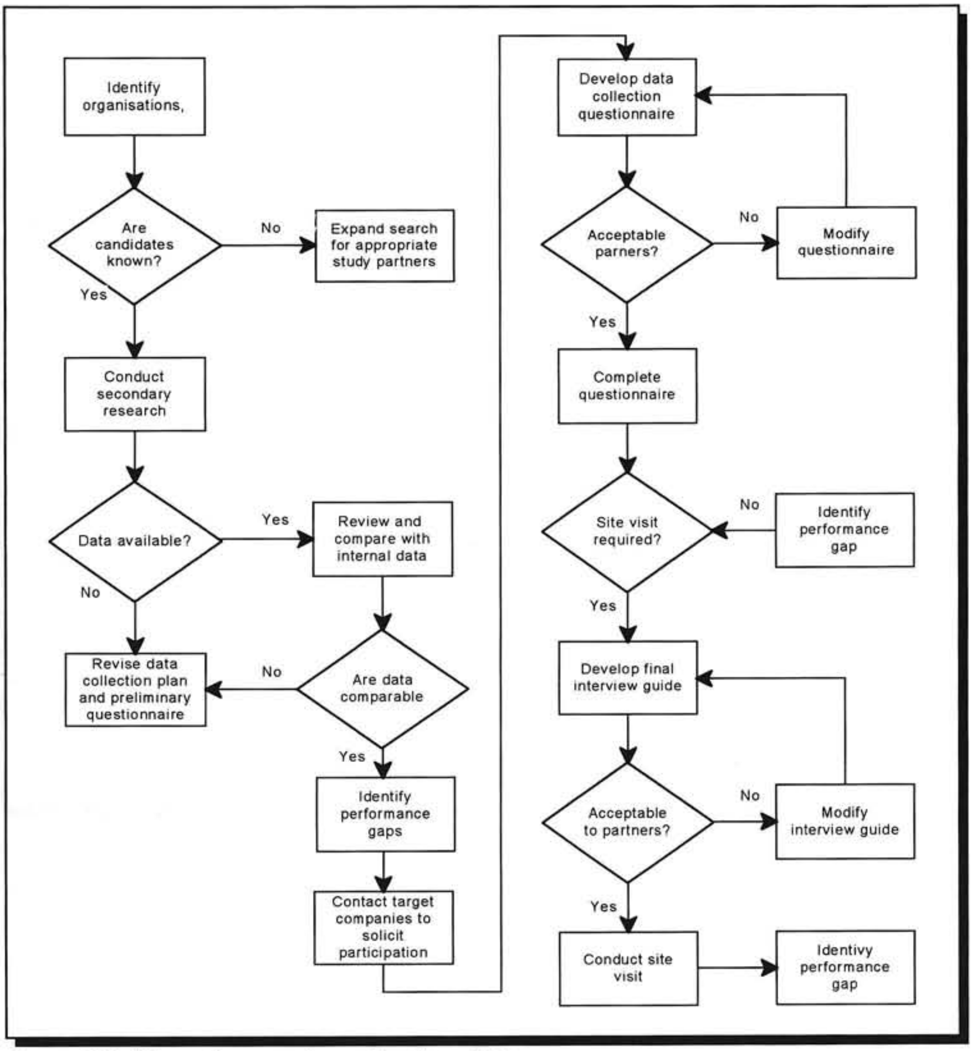


Figure 33: Flow diagram for collecting data

Finally, step four, improving by adapting process enablers, provides the bias for action that actualises benchmarking as a strategic change management process. The purpose of this step is to drive the selected improvements into the organisation by applying the knowledge learned during the benchmarking study. The Benchmarking Gap Closure process is schematically illustrated by **Figure 35**. This diagram shows performance as function of time.

Benchmarking in theory is something different from the actual application, as A. Rolstadås (edit.) book *"Benchmarking - Theory and Practice"* illustrates.

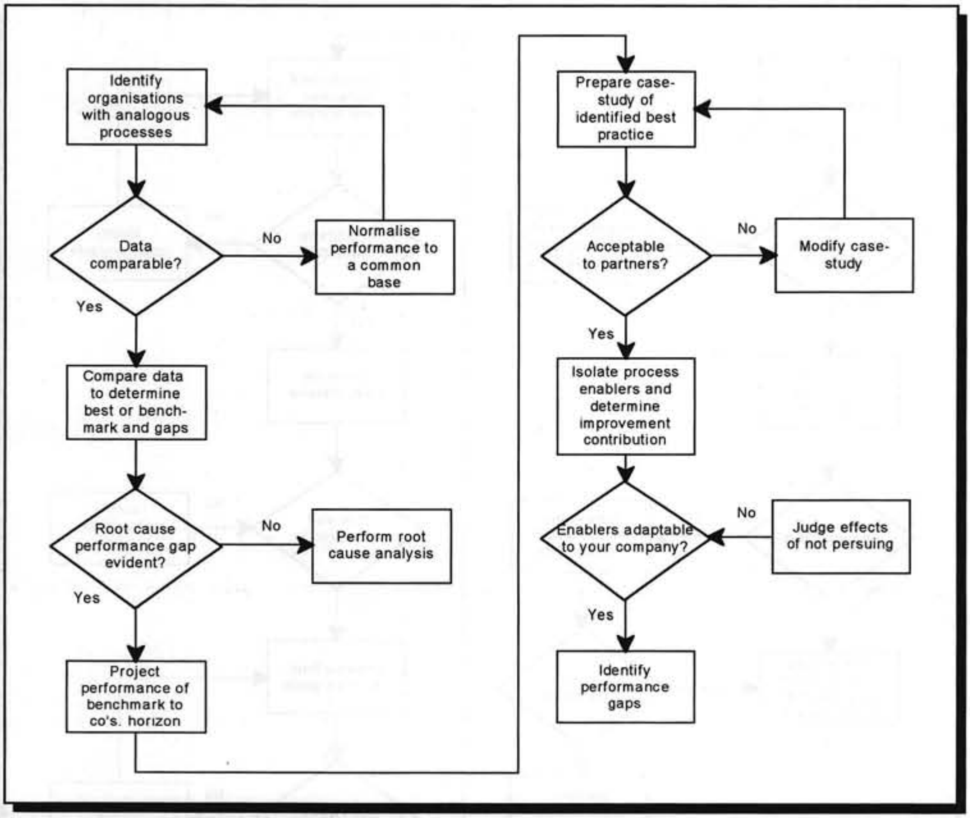


Figure 34: Analysing flow diagram

The book contains no applications from the transport and maritime sectors. The readers are invited to fill in this gap.

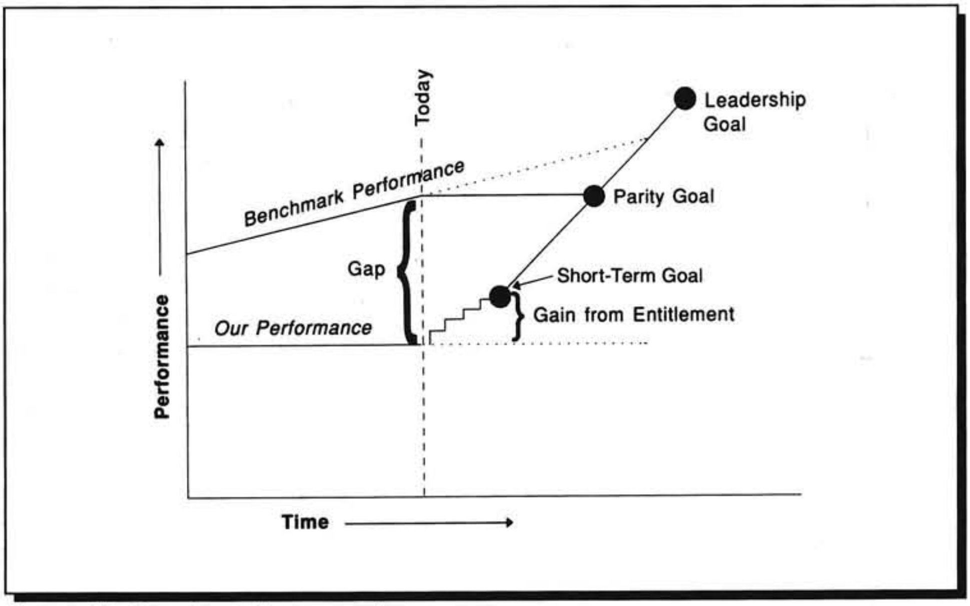


Figure 35: Benchmarking gap closure

CHAPTER 14: INTRODUCTION DESIGN INNOVATION CASE-STUDIES

The innovation theory is best understood with the help of concrete design innovation examples. The following chapters illustrate some of the design innovation in shipping methodologies, which have been discussed in the previous chapters. The final chapter (25) will summarise this methodology and propose a 12-step approach to increase the innovation content of design in shipping. The case-studies have not been executed on the basis of the new methodology; the design innovation in shipping methodology has gradually been developed out of the trial and error experience based on these case-studies. The eight case-studies have the following themes:

Chapter 15: Optimisation of small gas tankers
Chapter 16: Sea-river hatchless container ship
Chapter 17: Sea-river tug-barge car carrier
Chapter 18: Cylinder tank type chemical tanker
Chapter 19: Design of an integrated oil supply system
Chapter 20: Innovation in forest products shipping
Chapter 21: Innovation in shortsea shipping
Chapter 22: Decision support system for the planning of chemical tankers

These studies are briefly discussed below.

1. Optimisation of small gas tankers

The design process of small gas tankers is determined by the triangular relationship between the shipowner, the shipbuilder and the gas tank designer/builder. All three parties in this design process have different objectives, which are not always in line with one another. This may lead to a sub-optimal solution from the point of view of the shipowner. The design innovation of small gas tankers, which is in this case the optimisation of the tank configuration in relation to the ship's hull, is not a natural design goal because of these differing objectives.
T. Valentijn, made his master thesis work at the Faculty of Mechanical Engineering and Marine Technology with a large Norwegian gas tanker owner and operator on the optimisation of small gas tankers. He developed a specialised computer programme that makes it possible to establish the relationships between tank configurations, tank construction costs, the corresponding ship's hull and machinery cost and the operating cost. Based on this model it became clear that the owner could save a considerable amount of money if he chooses for a different, more simple tank configuration.

This case-study illustrates the rigorous approach that is necessary in order to optimise a specific ship type, and the prove that it may be worth the effort (read 'investment').

From a methodological point of view, it is interesting to note that at the time of the study (1989), few owners questioned the trend set by tank designers to use complex and expensive bi-lobe tanks, while this part of the vessel represents the single largest investment. Design innovation in small gas tankers should therefore always incorporate this simple, but rather basic investigation, which will not automatically come from the shipbuilder or the tank builder.

2. Sea-river hatchless container ship

Sea-river ships are characterised by a shallow water and air draught, which makes it possible for these ships to sail the seas and rivers with a relatively high deadweight. This may eliminate handling in a seaport, as they can be discharged directly up-river.
The sea-river vessel development is one which originated in the sixties in the former Soviet republic, and it spread readily since the 70s to Western Europe. The total fleet comprises some 1100 vessels, and is made up of various ship types, although the major part is dry cargo (multi-purpose).
In 1985 a project was started by myself and a number of Rotterdam-based companies, which were all involved in container shipping, in cooperation with a shipyard, Verolme Heusden, in order to develop a sea-river container ship with a maximum carrying capacity for the Rhine. The project, with the name NorthSea-Rhine Express, developed an innovative hatchless ship, with the unique ability to become a push barge on the Rhine, on top of the normal ship's capacity.
Ultimately, the project was shelved, as the service level was too low in relation to the existing shortsea container services, while an increase in service level created a massive overcapacity, which could not be justified by the container growth rates at that time.

From a design methodological point of view, the project clearly demonstrates the design trigger of maximisation of revenues, through the combination of three different transport markets, those of door-to-door containers, feeder containers, and inland barge containers. The idea of turning a seagoing vessel into a hundred metre push barge on the river Rhine, was an other basic innovation. In spite of all the creative effort, the major constraint remained the market size and its service requirements, which is a stumbling block for most of the innovation projects.
Design innovation in shipping should therefore consider in major detail the market prospects and the critical success factors of a new design in an advanced stage of the project. This is often difficult for the originator of the innovation, as he 'falls in love' with the concept and does not want to be confronted with bad news about the viability in the market place.

3. Sea-river tug-barge car carrier

Tug/barge combinations form a small niche market in shipping, in particular in Japan and North America. The concept has certain advantages which are in this case applied to the car transport market in North Western Europe. The novelty of this case-study is the use of the barge as a shallow draught car carrier on the river Rhine, and a normal (ballasted) tug-barge on the Northsea.
W. van Leeuwen did this design project as part of his master thesis work at the Faculty of Mechanical Engineering and Marine Technology of the Delft University of Technology in 1991 in cooperation with a large Rotterdam stevedoring company. As part of his preparation of the project, he visited several tug-barge companies in North America and made a trip on one of them in the U.S. Gulf. The design project was based on the transport requirements of a specific car manufacturer with various production plants in Germany, Belgium and the U.K.
The tug/barge concept proved to be a feasible alternative in financial and quality terms, but at the same time it implied a long term transport contract from this manufacturer if it were to be financially attractive from the shipowner's point of view. The dedicated car carrier with its specific design characteristics for sea-river operations made the secondhand value uncertain in case the contract should be cancelled.
The car manufacturer did not like to commit itself to one transport system, and wished to play the market, not so much for financial reasons, but from a point of view of flexibility and vulnerability to for example strikes.

From a design innovation methodological point of view the tug-barge project proved again very clearly that innovation in the car transport market is not only dependent on financially attractive rates, but rather on other commercial and strategic issues, which are difficult to gauge from the outside. It is therefore imperative to communicate in a very early stage of a design innovation project with the prospective user of the system and seek his guidance on these matters.

4. Cylinder tank type chemical tanker

In 1989 a Dutch consortium of a maritime research company and and a shipyard/ship designer worked on the design innovation of a sea-river chemical tanker, based on a tank configuration with many small cylindrical tanks. One of my students, R. Heijliger made his master thesis of this project, which has been published in an abbreviated form in the book *"Innovation in chemicals shipping"*.
One of the researchers, ir. E. Vossnack and myself, later on (1992) convinced a large Norwegian/Dutch chemical parcel tankers company to make a design study for a large chemical tanker based on the use of independent cylindrical stainless steel tanks. This study, which was done in cooperation with a manufacturer of stainless steel tanks - Holvrieka-Nirota - proved to be an attractive design innovation, but of course with a number of unproven design features and cost elements.

The design was superior to the existing standard parcel tankers built during this period, but it appeared a too steep departure from the current design and construction practices to convince the owner to give it a try. This is of course quite understandable as the ship's price tag was around US$80 million. One does not take chances with this kind of money involved.
The favourable operational characteristics and the conceptually attractive solution of the cylinder tank type chemical tanker, will - to my opinion - ultimately convince the chemical tanker operators to experiment with this concept. In particular when the existing Marpol regulations will become even more strict, and the pressure on companies to respect more the three R's of design: Re-duce, Re-use and Re-cycle.

From a design methodological point of view the lessons to be learned from this design project were mostly linked to the risk of investing in an unproven technology. In this case it was not a matter of market demand or a long term contract, but simply that the comparative cost of the new design had not been established on concrete tenders with shipyards, and the fact that chemical tankers are extremely expensive ships and a mistake in the operational or commercial success of the new design could be fatal for the company.

5. Design of an integrated oil supply system

This case-study is not so much an oil tanker design study in the narrow sense, but rather a global model of an oil supply system; a reformulation of the design problem. The case-study taken from a book by R.G. Coyle, clearly demonstrates the complexity of a ship design environment and the many tradeoffs that exist when designing and innovating a ship. Should an oil tanker be dedicated to a certain trade or should it be multi-functional and become a compromise for the various needs which may change over time?
The system dynamics methodology is particularly suited to visualise this complexity and simulate the impact of various design parameter assumptions on the model behaviour.
From a design innovation methodology point of view, the case-study shows that a ship is never an isolated asset, but always a part of a logistical system. A system, which dictates to a large extent the design requirements from a commercial, operational or economic perspective.

6. Innovation in forest products shipping

R. van der Lugt has a creative streak and was therefore very keen to experiment during his master thesis project with creativity techniques in the design innovation in shipping process in order to enhance the creativity content of such designs. Kai Levander and Sauli Eloranta of the Finnish Kvaerner Masa-Yards Technology company were interested to see how these creativity techniques could be explicitly used in a one man design process, and provided Van der Lugt with the opportunity to work in their office in Turku. At the time, 1992/93, the

Finnish forest products industry went through a through and the reduction of the share of the logistical cost of exports to the European continent seemed the only way to stop a further erosion of the Finnish export position of these forest products.
The Dutch shipowner Wagenborg Shipping, the largest operator on the Baltic Sea, supported the project which added to hands-on knowledge of the current shipping practices.
Van der Lugt concentrated his design innovation project on the paper reels transport, and came up with a very creative and attractive new concept, which was dubbed "reels-on-wheels". He graduated at the Faculty of Mechanical Engineering and Marine Technology by mid-1993 and the master thesis was reworked into a book, titled *"Innovation in forest products shipping"*, which was presented at the Pulp & Paper Industry Transport Conference in Antwerp in 1993, where it met with a mixture of enthusiasm and disbelieve.

From a design innovation methodology point of view, the reels-on-wheels concept represented such a relatively simple solution, which could attain the objectives of a substantial reduction of the logistical cost, but at the same time was so far removed from the current thinking that it seemed to most of the industry professionals many bridges too far in comparison with the current systems and technologies.
The case-study illustrates and documents clearly the use of creativity techniques in combination with rigorous naval architecture procedures and advanced calculation programmes. Nevertheless, it proves that gradual improvement innovations in the logistical system of forest products shipping are easier to accept and incorporate than a radical basic innovation. The only chances for a radical change exist, when all the industry participants are convinced that the current working practices have reached the limit of the performance S-curve and that a new S-curve should be started. In that case, they should know where to look!

7. Innovation in shortsea shipping

Shortsea shipping plays a major role in inter-European transport, but it has a drawback when competing in certain markets, such as the demanding container and swapbody (intermodal) segments. The reasons being a combination of constraints, especially in and around the ports. The Swedish industry located in the north of the country, wished to create an alternative for road and rail transport and commanded a study into the conditions under which such a high quality and low cost service could function. This study, made by MariTerm A.B. of Gothenburg, provided the basis for a thesis project of two of my students, C.J. Kleijwegt en H.B. van der Hoeven, which they completed in 1993. The essence of their work was, like MariTerm's study, to develop a new ship type, capable of being handled in port independent of the presence of stevedores, and at a phenomenal high handling rate and consequently low cost.
With the support of research grants from Sweden, The Netherlands and the European Commission DG VII, myself, and two other consultants continued with

a follow-up on both studies. Another student. T.J. Schmitter, contributed with his master thesis project on the more detailed design of the advanced selfloading and unloading unit load ship as well. The results have been published in 1994 in two books, and widely communicated amongst European transport professionals.
The books, titled *"Innovation in Shortsea Shipping"*, and" *Multimodal shortsea transport, the coastal superhighway"*, are summarised in this case-study.

The proposed innovations in the design of shortsea unitload ships demonstrate that major breakthroughs in handling efficiency could be achieved, but that only the implementation of a full scale operation, with a high sailing frequency, could begin to compete against the existing modes. This requires a relatively large investment from the shipowner, with no guarantee what-so-ever to make a decent return, or even worse, to survive the initial start-up phase. Innovation in shipping can in this case only take place when there is some sort of government back up in the financing. Without this support, the much talked about change from road-to-sea will not happen.
This case-study illustrates again that the financial constraints are too large, while the technical/operational issues could, in spite of their high level of innovation content, not compensate for this situation.

8. Decision support system for the planning of chemical tankers

Innovation in shipping does not only take place in the conceptual design of new ship types, but also in the many managerial functions that are performed within a shipping company. This is illustrated with the help of yet another master thesis project from D.J. Antvelink, done in Houston with Chemical Tankers of America (CTA), on which he graduated early 1995, under the joint supervision of Prof. Evers and myself.
The objective of his work was to develop a decision support tool for the commercial department of CTA, while booking last minute spot cargoes and at the same time taking into account all the constraints imposed by the nature of cargoes, the ship type and the rules and regulations such as on compatibility of cargoes or the US Coastguard.
A typical small tanker as managed by CTA has fifteen tanks, with different qualities, such as coated or stainless steel, and the number of combinations of cargoes that can be planned is quite large, while at the same time the freight revenues differ from cargo to cargo, but also the cost of for example tank washing.
Antvelink studied the cargo booking and planning procedures of three chemical tanker companies and developed on the basis of this knowledge a computer model that was capable of planning the cargoes, and at the same time showing the most profitable combinations, taking into account all the constraints.
The programme meant a real innovation in commercial management, but its full scale implementation cannot be done in isolation. It requires the change and adaptation of administrative, operational and commercial procedures.

Management innovation as examplified by the decision support tool offers for shipping companies problably the best effort-performance/reward ratio as the investment in time is generally speaking small, while the results can be far reaching. Therefore, shipping lines should be stimulated to develop support tools in processes that are hitherto considered to be beyond simulation modeling boundaries. One such area is the scheduling of a fleet of ships. A number of master thesis projects are currently underway to show that a lot can still be achieved in this domain.

CHAPTER 15: OPTIMISATION OF SMALL GAS TANKERS

The design of a small chemical gas tanker is the result of the interaction between three parties:

- The shipowner, who defines the main specifications and pays for the ship;
- The naval architect/shipbuilder, who is responsible for the detailed design of the hull, machinery and construction:
- The tank manufacturer, who is responsible for the cargo containment design and construction.

Each party has its own objectives. The owner wants low investment and operating/running costs, the shipbuilder wants minimum production costs and the tank manufacturer wants to design (complicated) tanks, which fill the entire hull space. The compromise that is the result of these different objectives, is not necessarily the optimal solution for the shipowner.

This study, which was conducted in cooperation with a Norwegian shipowner, shows that there are many ways to design a tank configuration for small (chemical) gas tankers.
It also shows that it is worthwhile for the shipowner to spend some extra funds on the design process, as the potential savings could be in the order of 10-15 percent of the initial investment.

15.1 An introduction in gas tanker techniques

15.1.1 Ship types

According to the I.M.O.s *"Code for the construction and equipment of ships carrying liquefied gases in bulk"*, there are three types of ships allowed to carry liquefied gases. Type IG serves for the transportation of the most dangerous products and types IIG/IIPG and IIIG for progressively less dangerous products. Accordingly, a type IG ship should survive the greatest extent of hull damage and its cargo tanks should be at the greatest distance inboard from the shell plating. The type of the ship has an effect on several design aspects. Most of the gas carriers are type IIG or type IIPG ships.

The following standards of damage should be applied to the design of the ship:

- *"A type IG ship should be capable of sustaining damage anywhere over its length";*
- *"A type IIG ship with a length of 150 m. or less should be capable of sustaining damage anywhere in its length, except involving either of the bulkheads bounding a machinery space located aft";*
- *"A type IIG ship of 125 m. or longer should be capable of sustaining damage anywhere in its length except involving transverse bulkheads spaced further apart than the longitudinal extent of damage listed hereafter...."*
- *"A type IIIG ship shorter than 125 m. in length should be capable of sustaining damage anywhere in its length except involving transverse bulkheads spaced further apart than the longitudinal extent of damage listed hereafter and except involving damage to the machinery space".*

The cargo tanks should be located at the following minimum distances inboard *(Source: I.M.O. Gas Carrier Code)*:

- Type IG ships: *"from the shell plating not less than the transverse extent of damage specified on page 5 and 6 and from the moulded line of the bottom shell plating at the centre line not less than the vertical extent specified on the same page, and nowhere less than 760 mm. from the shell plating";*
- Type IIG/IIPG and IIIG ships: *"from the moulded line of the bottom shell plating at the centre line not less than the vertical extent specified on page 5 and 6, and nowhere less than 760 mm from the shell plating".*

15.1.2 Transportation condition of liquefied gases

The transportation condition of liquefied gases is determined by the pressure and the temperature at which the gases are transported. Three conditions can be distinguished:

- Fully-pressurised (FP);
  In the fully-pressurised condition, the gases are carried in pressure vessels that can withstand the maximum pressure likely to be met in service (usually 18 bar). The cargo is kept liquid using pressure only. The temperature of the cargo is equal to the ambient temperature.

- Semi-pressurised (SP/SR and SP/FR);
  Semi-pressurised means that the ship can keep the cargo pressurised and cool it simultaneously. The first ships with that ability were the semi-pressurised/semi-refrigerated (SP/SR) ships which could cool the cargo

down to about -10°C. Ships built since, can cool the cargo to -48°C (SP/FR), or even to -104°C (SP/FR) for ethylene. This means that these ships can carry their cargo not only under pressure and semi-refrigerated, but under atmospheric pressure and fully refrigerated as well. Semi-pressurised ships normally have cargo tanks that use the available space better than fully-pressurised ships. The tanks are lighter, but a bit more complicated than the pressure vessels of FP ships, so they cost more. A refrigeration system is required and cargo pumps should be installed. There are major differences in the building costs of FP and SP ships, the operational costs differ because of the fuel used by the refrigeration plant.

- Fully refrigerated (FR).
  Fully refrigerated ships cool their cargo and carry it under atmospheric pressure. Because the tanks are not subject to high pressures the cargo tanks can have almost every normal tank form. Therefore, it can use the available cargo space better than ships of the other types. Tanks can be much larger and, for any size, much lighter.

15.1.3 Tank categories

The *"Code for the construction and equipment of ships carrying liquefied gases in bulk"* gives classifications of tanks for the transportation of liquefied gases in bulk.

Integral tank

Integral tanks are formed along the inner hull, the bulkheads and the deck. The tanks form a structural part of the ship's hull and are influenced in the same way and by the same forces that stress the adjacent hull structure.
The design vapour pressure P_0 should normally not exceed 0.25 kP/cm^2. If however, the hull scantlings are increased accordingly, P_0 may be increased to a higher value but less than 0.7 kP/cm^2. The lowest temperature in any part of the hull structure should not get below -10°C. A lower temperature may be accepted after special considerations. The hull of the ship acts as a secondary barrier.

Membrane tank

Membrane tanks are non-self-supporting tanks that consist of a thin layer (membrane) supported through insulation by the adjacent hull structure. The membrane is designed so that thermal and other expansion or contraction is compensated without undue stressing of the membrane. The design vapour pressure P_0 should normally not exceed 0.25 kP/cm^2. If however, the hull scantlings are increased accordingly, P_0 may be increased to a higher value but less than 0.7 kP/cm^2.

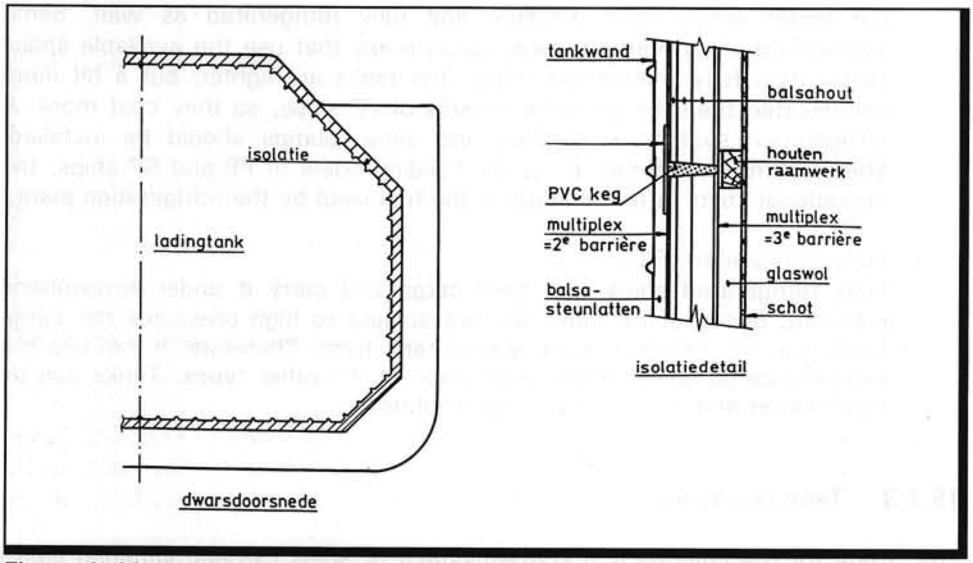


Figure 1: Membrane cargo tank

Semi-membrane tank

The semi-membrane tanks are non-self-supporting tanks and consist of a layer, parts of which are supported through insulation by the adjacent hull structure. Rounded parts of this layer connecting the above-mentioned supported parts are designed also to compensate the thermal and other expansions and contractions.
The design vapour pressure P_0 should not normally exceed 0.25 kP/cm^2. If however, the hull scantlings are increased accordingly, and consideration is given to the strength of the supporting insulation, P_0 may be increased to a higher value but less than 0.7 kP/cm^2. The semi-membrane tank requires a secondary barrier.

Independent tank

Independent tanks are self-supporting. They do not form part of the ship's hull and are not essential to the strength of the hull. The three subcategories of independent tanks are:

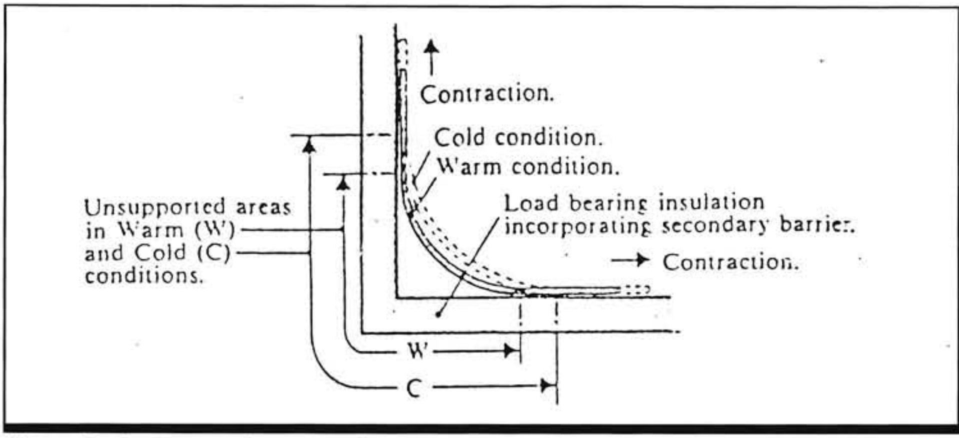


Figure 2: Semi-membrane tank

1. *Independent tanks type A* are designed primarily using *Recognised Standards of classical ship-structural analysis procedures.* Where such tanks are primarily constructed of plane surfaces (gravity tanks), the design vapour pressure P_0 should be less than 0.7 kP/cm^2.
2. *Independent tanks type B* are designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics. Where such tanks are primarily constructed of plane surfaces (gravity tanks) the design vapour pressure P_0 should be less than 0.7 kP/cm^2.
3. *Independent tanks type C* (also called pressure tanks) are tanks meeting pressure vessel criteria and have a design pressure that meets special, minimum, tank dependent criteria.

Tanks of type A should have a complete, and tanks of type B a partial secondary barrier. Tanks of type C do not require a secondary barrier.

Internal insulation tank

Internal insulation tanks are non-self-supporting and consist of thermal insulation materials that contribute to the cargo containment and are supported by the structure of the adjacent inner hull of an independent tank. The inner surface of the insulation is exposed to the cargo.

The design vapour pressure P_0 should normally not exceed 0.25 kP/cm^2. If however, the cargo containment system is designed for a higher vapour pressure P_0 may be increased to such higher value, but not exceeding 0.7 kP/cm^2 may be accepted provided the internal insulation tanks are supported by suitable independent tank structure.

Requirements of a secondary barrier

Where cargo temperature at atmospheric pressure is below -10°C, a secondary barrier should be provided when required. Its purpose is to act as a temporary containment for any envisage leakage of liquid cargo through the primary barrier. When the temperature of the cargo at atmospheric pressure is not below -55°C, the hull structure may serve as a secondary barrier.

15.1.4 Tank types

Spherical tank

The spherical tank has an ideal form for the transportation of liquefied gases under pressure. The stresses in the tank's shell are uniformly distributed, so a relative thin tank shell is sufficient to withstand the pressure from within the tank. This results in a light and cheap tank. The tanks can be built independently of the ship, they do not have to be built by the shipyard.
A disadvantage is that the tank is supported by a cylinder resting on the ship's double bottom. This cylinder is a relatively heavy component that raises the total weight of the containment system. A second major disadvantage is that the available space on board the ship is not used in an optimal way. This leads to a relative large and expensive ship. Also, the centre of gravity of this tank type is fairly high. The capacity of the spherical tank only depends on the diameter of the sphere.

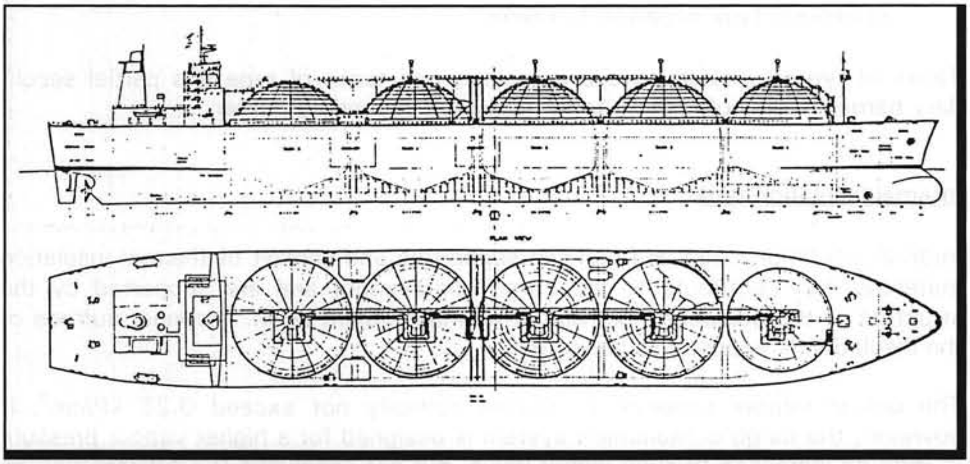


Figure 3: Spherical cargo tanks

Cylindrical tank

The advantage of the cylindrical tank over the spherical tank is that the form of the ship's hull can be more ideal. A smaller (cheaper) ship with a lower fuel consumption can be designed. The centre of gravity of the cargo in a cylindrical tank is lower than that of a spherical tank. This has a positive influence on the stability of the ship. The cylindrical tank is normally designed to the independent tank type C standards and does therefore not require a secondary barrier.
The cylindrical tank has two design parameters, the diameter and the length of the cylinder. The tank capacity is limited by the maximum thickness of the tank shell. The greater the diameter and the higher the design vapour pressure, the thicker the tank shell must be. The thickness of the tank shell is limited by welding problems and mechanical characteristics of the material. The length of the tank is limited by the length of the containment space.

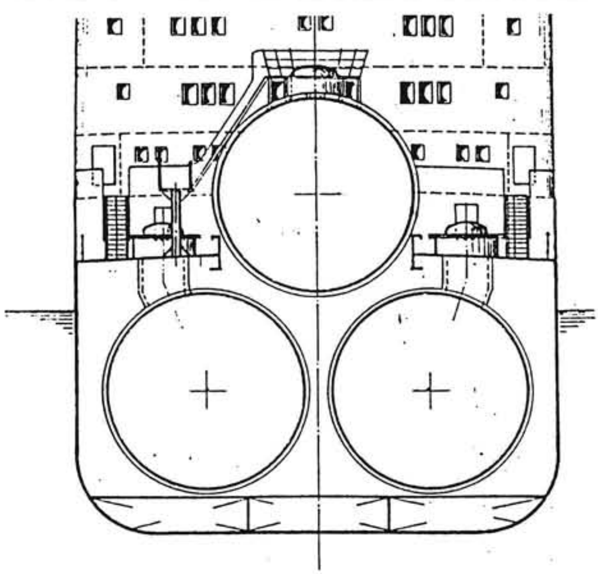


Figure 4: Cylindrical cargo tanks

The bi-lobe tank

The bi-lobe tank, or twin lobe tank, consists of two identical parallel horizontal cylinders that intersect. The greatest advantage of this tank type is that the form of the tank resembles the form of the hull more than the cylindrical tank. The centre of gravity of the bi-lobe tank is lower than that of the spherical tank.

In the middle of the tank, between the two intersections of the cylinders, a longitudinal bulkhead is placed that divides the tank into two lobes. The longitudinal bulkhead reduces the free surface of the liquid cargo. In the top, the bulkhead has several holes so that the lobes share the same vapour space. The bi-lobe tank is normally designed to the independent tank type C standards and does therefore not require a secondary barrier. In the fore end of the ship, the breadth may not be sufficient to place a bi-lobe tank. To exploit the advantages of the bi-lobe tank further, a conical bi-lobe tank can be used. The conical bi-lobe tank has one part that has a bi-lobe section with a constant diameter and one part that has a decreasing diameter of the lobes and a decreasing distance between the centres of the lobes.

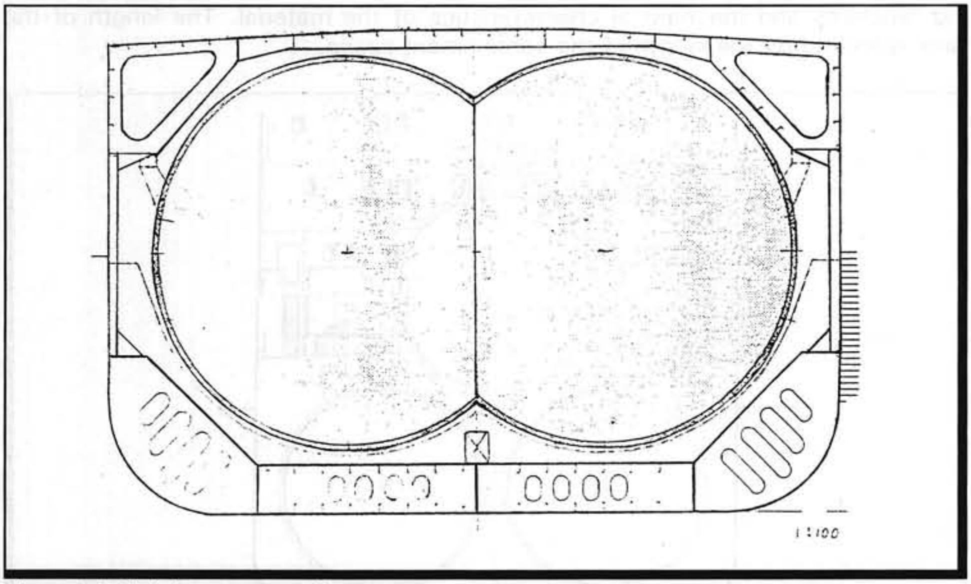


Figure 5: Bi-lobe cargo tank

The bi-lobe tank has three design parameters: the diameters of the lobes, the length of the tank and the distance between the centres of the lobes.

Compared to a cylindrical tank with the same capacity, the shell of the bi-lobe tank is thinner. Although the area of the bi-lobe tank is larger, usually the bi-lobe tank is lighter. As with the cylindrical tank, the maximum capacity depends on the maximum thickness of the tank shell.

The disadvantages of the bi-lobe tank compared to the cylindrical tank are:

- The bi-lobe tank is more complicated to make, so more expensive. This is especially true for the fore end of the ship, where the limited breadth demands a conical bi-lobe tank;
- Two deepwell pumps must be used, one at each side of the longitudinal bulkhead. The cylindrical tank needs only one deepwell pump.

Tri-lobe tank

The tri-lobe tank consists of three identical parallel cylinders, two on the bottom and one on the top, which intersect. It looks like a bi-lobe tank with another lobe on top of it. The tri-lobe tank has three longitudinal bulkheads, one vertical and two cross. This tank type meets the I.M.O. independent tank type C requirements.

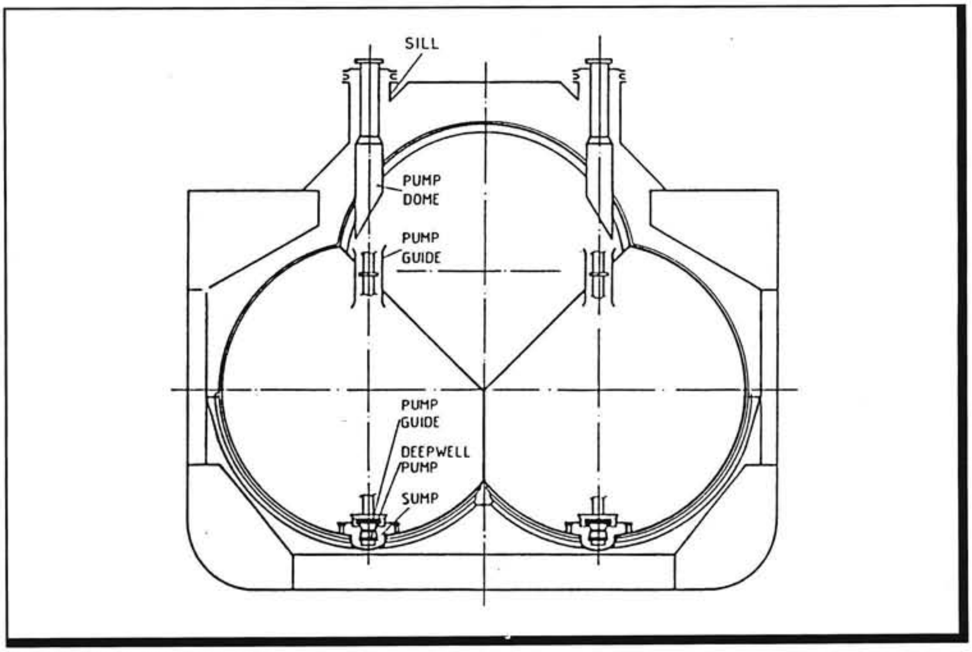


Figure 6: Tri-lobe tank

The tri-lobe tank has four design parameters: the diameter of the cylinders, the length of the tank, the horizontal distance between the centres of the two lower lobes and the distance between the centre of the upper lobe and the centres of the lover lobes.

The advantage over the other tank types is that the tri-lobe tank uses the available space better. A disadvantage is that the centre of gravity of the tri-lobe tank is high.

Multi-lobe tank

The multi-lobe tank consists of several identical, parallel cylinders, which intersect. The cylinders can be brought together in several ways. This tank type is a development of the bi-lobe and tri-lobe principle. Any configuration is possible, for instance three horizontal intersecting cylinders, of two bi-lobes on top of two bi-lobes. The advantage over the bi-lobe tank is the possible utilisation of the ship's space and the possible adaption to the ship lines. Comparing a horizontal multi-lobe tank and a tri-lobe tank, the tri-lobe tank has 10% more capacity and 30% more weight. But the weight of the whole ship differs only 3 to 4%.

Prismatic tank

The prismatic tank has one of the most ideal forms. All available space in the ship's hold can be used as cargo space. However the cargo should be carried at atmospheric pressure because the form of the tank cannot resist high pressures. This means that the design vapour pressure may normally not exceed 0.25 kP/cm^2. The prismatic tank can be an integral tank, a membrane or semi-membrane tank, or an internal insulation tank. Therefore, this tank type requires a secondary barrier.

Multi-vessel system

Two systems based on the same principle, are the LGA 'zellentank system' and the Linde 'multi-vessel system'. These systems consist of many interconnected cylinders. Unlike the bi-, tri- and multi-lobe systems, these cylinders do not intersect. With the LGA system, the cylinders are placed transverse horizontally in the ship; with the Linde system, the cylinders are place vertically. The cylinders can also be placed horizontally in longitudinal direction.

The advantages of these tank systems are a good utilisation of the ship's space, the possibility to adjust the cargo tank to the ship's lines, the possibility to produce standard (and cheap) cylinders and no secondary barrier is required (independent type C tank). When the diameter of the cylinders is smaller, compared to the ship dimensions, the ship's cargo space can be used better, but the outer area of the cylinders is large and the tanks are heavier.
Disadvantage is that they are difficult to access. This is important for the cleaning of the tanks. The loading, refrigeration, discharging of cargo, and inerting and purging of the tanks are more difficult as well.

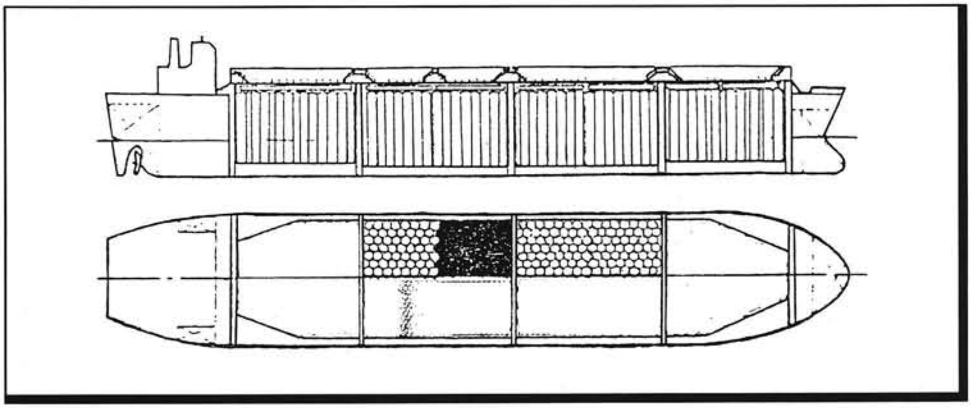


Figure 7: Multi vessel system

Ocean Phoenix system

The Ocean Phoenix tank resembles the multi-lobe tank. The multi-lobe tank only has lobes in the transverse section, this tank has lobes in all three directions. This tank was designed in the first place for the transportation of LNG under pressure, but while maximum gauge pressure can reach up to 4 bar, LPG and liquefied chemical gases can be carried as well. Over all, the tank looks rectangular, so a good utilisation of the ship's space can be achieved.
The tank is designed according to pressure vessel rules, so no secondary barrier is required.

Tank types and tank categories

Table I shows which tank types can be used with specific transportation conditions. **Table II** shows which tank types can be used with specific I.M.O. tank categories.

Integral tanks are used only in old ships (older than 15 years). The reason is that the forces that act on the ship's hull also act on the cargo tanks. The tanks need to be strong and are therefore expensive. Membrane and semi-membrane tanks are only used in LNG tankers. These tanks are very expensive and more vulnerable than the independent tanks.

Generally, if a ship is semi-pressurised, independent tanks type C are used; if a ship is fully-refrigerated, independent tanks type A or B are used.

Tank type	FP	SP/FR	FR
Spherical	X	X	X
Cylindrical	X	X	X
Bi-lobe		X	X
Tri-lobe		X	X
Multi-lobe		X	X
Prismatic			X
Multi-vessel	X	X	X
Ocean Phoenix system		X	X

FP fully-pressurised
SP/FR semi-pressurised/fully-refrigerated
FR fully-refrigerated

Table I: Possible transport conditions

Tank type	In-tegral	Mem-brane	Semi-membr.	Ind A	Ind B	Ind C	Internal insulat.
Spherical				X	X	X	X
Cylindrical				X	X	X	X
Bi-lobe				X	X	X	X
Tri-lobe				X	X	X	X
Multi-lobe				X	X	X	X
Prismatic	X	X	X	X	X		X
Multi-vessel				X	X	X	X
Ocean Phoenix				X	X	X	X

Table II: Tank types and categories

15.1.5 Products

Gas carriers transport several products: Liquefied Petroleum Gas (LPG), ammonia and other chemical gases. Liquefied Natural Gas (LNG) is transported by quite different types of ships.
Normally ammonia is transported in parcel sizes of about 24,000 m^3, which is beyond the capacity of the ships in this study, so it is left out of consideration.

LPG is a generic term covering light hydrocarbons. There are two main types of LPG: propane and butane. These products are transported separately or mixed. Propane and butane are mainly used as energy sources. Demand for LPG is made up of several submarkets. One important sector is the residential market where 'bottled' gas is used to provide fuel for heating and cooking where electricity and natural gas are not available. Another source of demand for gases is automotive fuel. LPG is also used ad an industrial fuel, for power generation and as a chemical feedstock.

Chemical gases that are transported, are the three major olefins: ethylene, propy lene and butadiene, and also vinyl chloride monomer (VCM). Other chemical gases transported are butylene, hexine and propylene oxide.
Ethylene forms the cornerstone of the chemical gas market, as most propylene and butadiene output arises as co-product during ethylene production. The main feedstocks are naphtha/gasoil, propane/butadane and ethane. Additional propylene is derived from oil refineries, used for upgrading the heavier components of the oil barrel to gasoline.

VCM is a material further down the chain from raw material to final product than the olefins. It is composed of about 50% ethylene, and also contains chlorine.

15.2 Factors that influence the tank configuration

This section describes the most important factors that influence the tank configuration of gas carriers. Not all factors can be easily quantified, but they all should be taken into account when deciding on the cargo tank configuration.

15.2.1 Trade restrictions

A severe restriction posed on the type of tank that can be used for a gas carrier, is the capability to resist pressure. In trades where small ships are used, normally the cargo is transported fully-refrigerated (FR). However, many loading

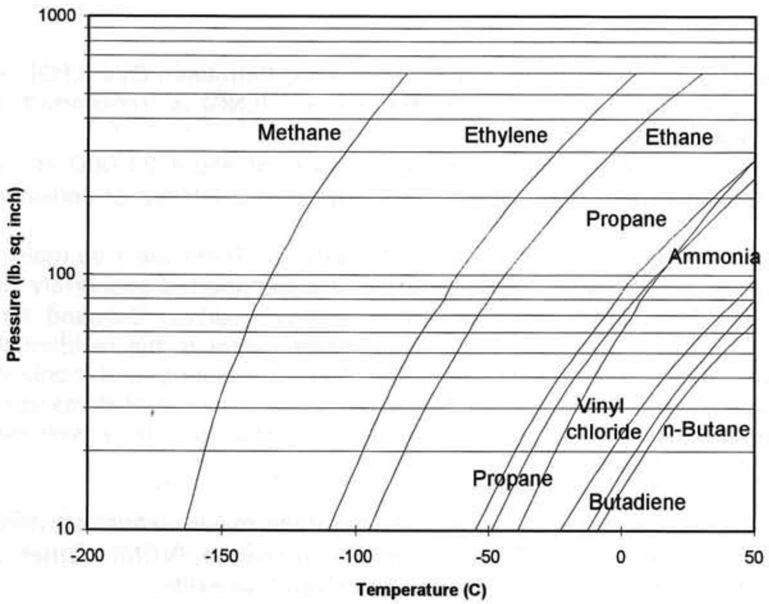


Figure 8: Temperature/vapour pressure relationship of selected ship-borne gases

terminals are not able to deliver the gas fully-refrigerated, for example in South American and Mediterranean terminals. The cargo is loaded at higher temperatures than the boiling point.
In order to load a sufficient amount of cargo when loading a cargo with a temperature above its boiling point, pressure is allowed to build up inside the tank. The maximum pressure the tanks are to resist depends on the temperature of the cargo being loaded. Normally the design pressure varies from 4 to 8 bar. The cooling capacity of the ship is not sufficient to cool down an above FR cargo above its boiling point while loading, and still maintain a reasonable loading rate of about 100 mt/h.
The cooling capacity is designed primarily to keep the temperature of the cargo at a certain level, the transportation temperature. The cooling capacity is used to cool down the cargo during transportation, if the discharge temperature is lower than the load temperature. A normal cooling capacity of these ships is one centigrade per day.

To build a ship with enough cooling capacity to cool down the cargo to FR while loading, is a solution. The extra costs of the cooling installation may be compensated by the extra revenues. However, more and more terminals are delivering at FR temperature. On the other hand, a ship that is capable only of transporting the cargo at atmospherical pressure would have a too low flexibility level.

This means that the trade poses a restriction on the type of tank that can be used for these gas carriers, the tanks need to be able to resist pressure. The choice of the tank type is restricted to the independent tank type C (cylindrical, spherical and bi-lobe tanks).

15.2.2 Flexibility restrictions and demands

Smooth and successful operation of a gas carrier requires a certain level of flexibility, in particular in the small trade, with a large number of relatively short distances, flexibility is required. In this paragraph, the most important flexibility demands are described.

The amount of flexibility demanded by the shipowner depends on the trade the owner has in mind for the ship and how much is known of the routes the ship will sail. If, for instance, the ship will be used in a long term contract (one cargo, one route), not a lot of flexibility is necessary. If, on the other hand, the ship will be used on the spot market, a good flexibility will be required. The final decision is made by weighing the advantages (and disadvantages) of flexibility and the costs of flexibility.

<u>Cargo flexibility</u>

Cargo flexibility comes forward into the number and type of cargoes a ship can transport, and the effort it takes to change cargoes:

- The types of cargo the ship can transport:
  Normally, the cargoes are transported fully-refrigerated. This means that the material of the tanks must be able to withstand low temperatures. If a ship is designed to transport ethylene (boiling point: -104 °C at atmospheric pressure), 5% nickel steel must be used. Otherwise, low temperature carbon steel (mild steel), which is cheaper.
- The number of segregated cargoes a ship can transport;
  In particular in the chemical gas trade, the parcel sizes are small. Sometimes a few cargoes can be transported simultaneously, thus avoiding ballast trips. Segregated transportation requires more and smaller cargo tanks, separated reliquefaction systems and separated piping.
- Changing grades;
  In particular when operating in the spotmarket for chemical gases, a ship needs to change grades rapidly. Sometimes the two successive cargoes are non-compatible, so inerting, purging, and cleaning is required.

If a ship has a large inert gas generator, the time to inert the cargo tanks before gas-freeing is short, thus giving a high level of flexibility on this point.

Tank cleaning sometimes has to be done by actually going into the tank and cleaning the tank with water and scrubbers (waterwash). The trouble it takes to clean the inside of a cargo tank with a waterwash depends on the type, the form and inner area of the tank. As one can imagine, a cylindrical tank is easier to clean than a bi-lobe or spherical tank.

Operational flexibility

Operational flexibility concerns the possible tasks a ship can perform and the ease with which it performs these tasks:

- Load and discharge capacity;
  The time spent in the port loading and discharging is determinded by the capacity of the cargo pumps, the cooling capacity on the intake of the cargo, and the warming up capacity on the discharge of the cargo. Normally, the load and discharge time spent in port when FR is about 15 hours.
- Shallow draught demand;
  A very important demand on the configuration of the cargo tanks is the amount of cargo that can be loaded in harbours with shallow draught. A number of harbours in South America and India have a draught restriction of about 5 m.
  When a ship must load in these harbours, a ship with a relatively small draught is better off than one with a large draught.
- Slack condition demand;
  A gas carrier often has stability problems. In the design phase the damage stability is sometimes problematic, and slack condition stability might cause problems as well. Slack stability is important, because it is common to load a cargo in one port and discharge it in several others, so the ship has to sail with some of its cargo tanks partly filled.

15.2.3 Costs and benefits

Generally, the cheapest designs with the same characteristics will prevail. Extra flexibility of the ship (above the minimum required flexibility level) could give extra earning power to the ship, but also costs money. It is up to the shipowner to decide how much extra money he is willing to pay for this extra flexibility. The costs of the ship can be divided into:

- The capital costs;

- The operational costs.

The capital costs can be divided into the building costs of the ship and the costs of the cargo containment system; they can best be considered apart because the shipyard generally buys the complete cargo containment system from a third party.

15.2.4 Schematic overview of factors that influence the design process

A computer model was made to develop different cargo tank configurations. **Figure 9** shows the main level of the gas carrier design process. The design process can be divided into five steps, they are:

1. Choose/change cargo tank configuration;
2. Design cargo tanks;
3. Design ship;
4. Determine costs;
5. Compare results with previous configurations.

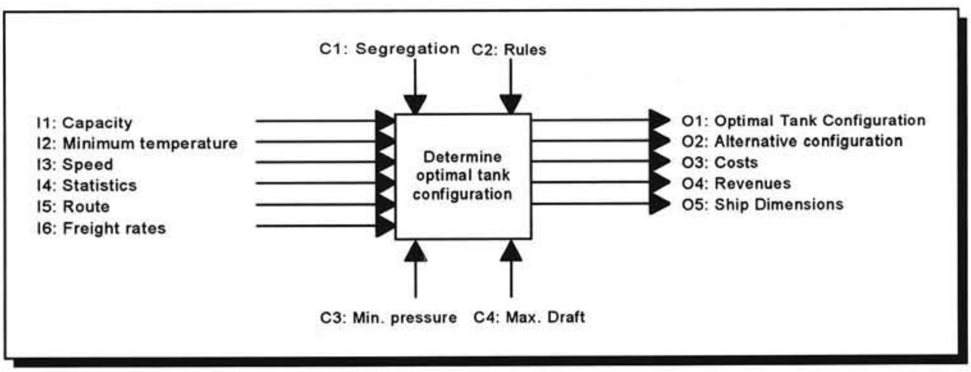


Figure 9: Main level design model

In step 1, a tank configuration, the number of tanks and for each tank the type and the dimensions, are chosen.
In step 2, the cargo tanks are 'designed', i.e. for each tank the capacity, the weight and the insulated area are calculated.
In step 3, the ship is 'designed'; the ship dimensions depend heavily on the tank configuration.
In step 4, the costs of the total ship are calculated, the initial building costs as well as the operational costs per month.

This process is iterative, after the comparison is made, in step 1 the cargo tank configuration is changed and the process starts all over again. As mentioned before, the starting point of the design process is the cargo tanks, the ship is designed around the tanks. It is possible do the opposite; start with the ship's hull and then design the tanks in an optimal way. The shipowner's starting point, the total capacity, should be the starting point of the design process as well. **Figure 10** shows these steps, each with its own input-, control- and output parameters. Of course often the output of one step is the input of another. After the tank capacities have been calculated, it might be necessary, in case of a low tank capacity, to go back to step 1 immediately after step 2. This means a sub-iteration in the design process. Other possible sub-iterations are:

- After step 3 (*design ship*), in case of a too large draught, go back to the start of step 1;
- After step 3, when the ship dimensions are calculated, go back to step 2 (design tanks) because the thickness of the tank shell depends on the ship dimensions;
- After step 3, should the ships damage stability prove to be insufficient, go back to step 1 (change tank configuration).

Figure 11, Figure 12 and **Figure 13** show the detailed processes in respectively the steps 3, 2 and 4. The activities in step 2 (design tanks) are:

- Calculate the cargo tank capacities;
- Calculate the tank shell areas;
- Calculate the tank shell thicknesses;
- Calculate the tank weights.

The activities in step 3 (design ship) are:

- Determine the dimensions of the ship;
- Calculate the weight of the ship;
- Calculate the resistance and the power of the ship;
- Calculate the weight of the machinery;
- Check the damage stability of the ship.

There are a few sub-iterations in step 3. For instance, the length of the machinery room depends on the installed power, which depends on the resistance of the ship, which depends on the length of the ship, which depends on the length of the engine room.
Another sub-iteration is the draught of the ship. The draught depends on the weight of the ship, which depends on the weight of the engine room, which depends on the installed power, which depends on the resistance of the ship, which depends on the draught of the ship.

In the following sections the relations between the cargo tank configuration and the costs of the ship are discussed. This will make it possible to weigh the costs against the benefits in order to come to an optimal tank configuration.

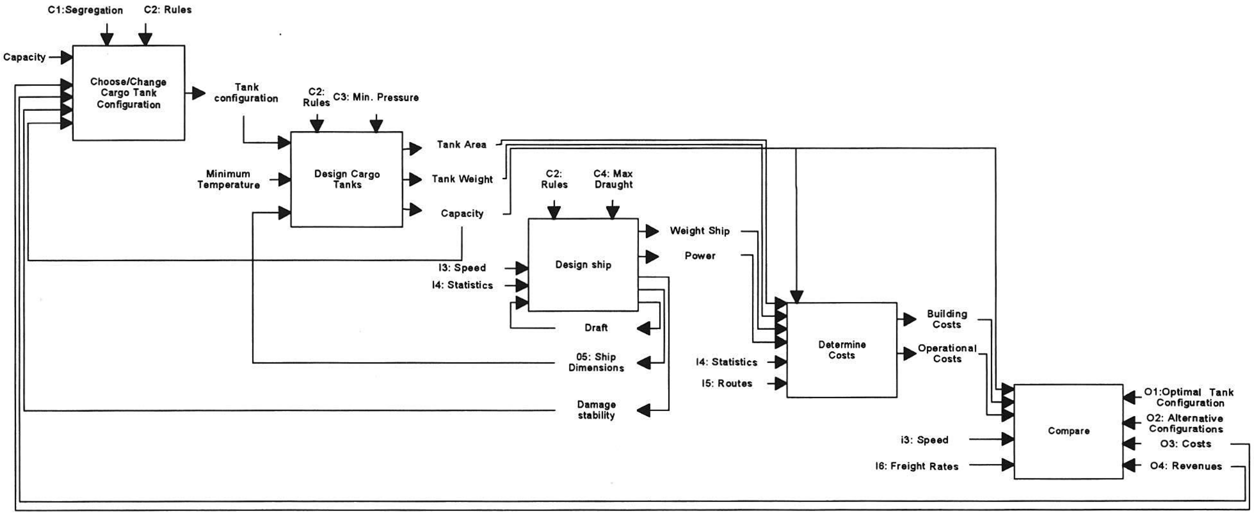


Figure 10: Design model overview

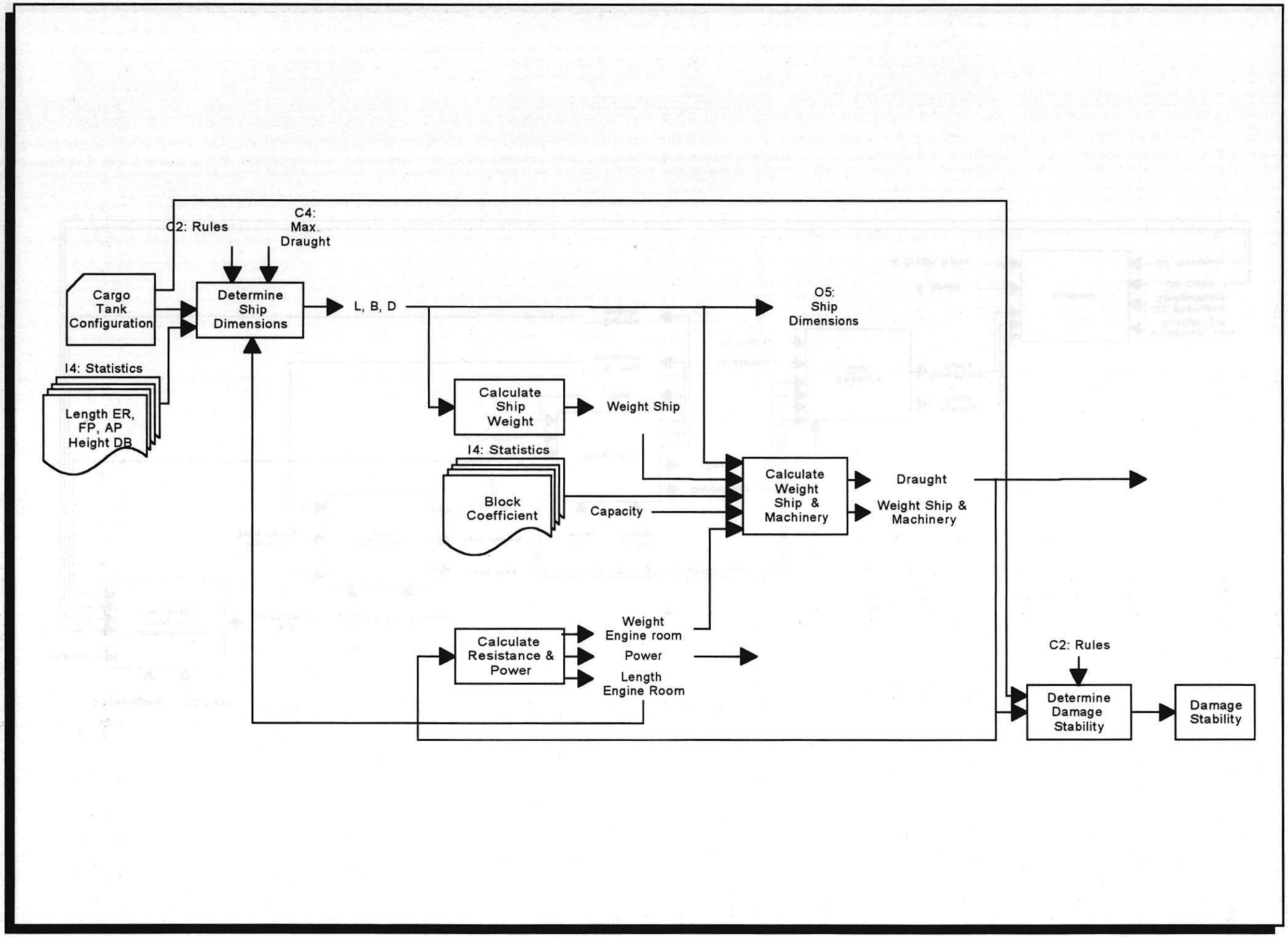


Figure 11: Step *Design ship* in detail

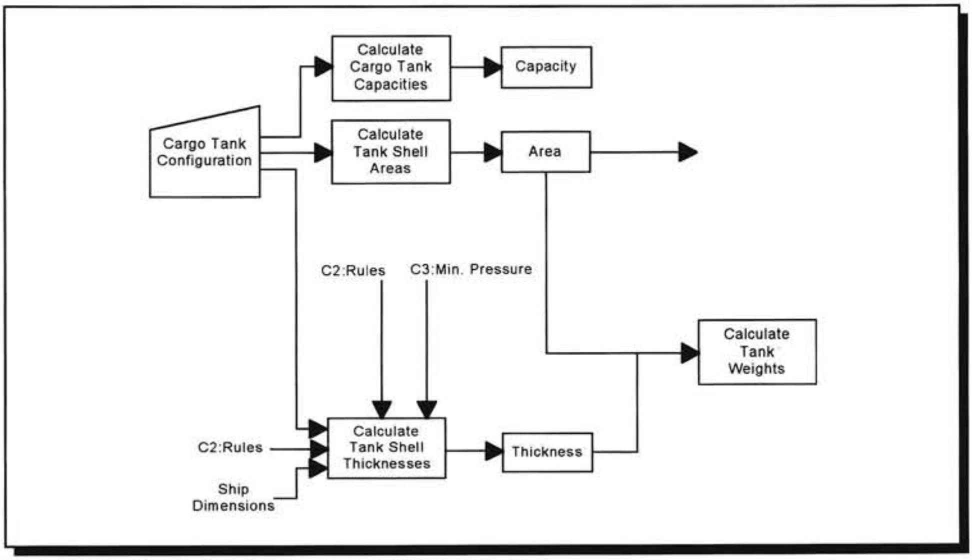


Figure 12: Step *Design cargo tanks* in detail

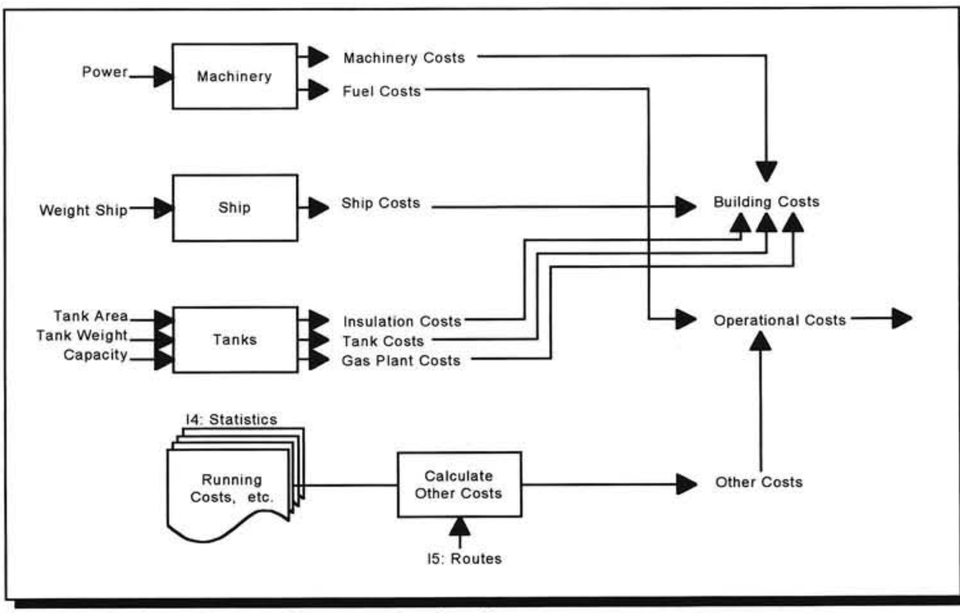


Figure 13: Step *Determine costs* in detail

Furthermore, some methods for the ship design are worked out, in particular a power prediction, a damage stability calculation and a light weight ship calculation. Some of these relations and methods are based on statistics.

15.3 Relation between dimensions, shell thickness and weight of the tank

The weight of the tanks depends on its size and thickness, and on the specific weight of the material it is made of. The thickness of the shell of the tank depends on the design pressure, the dimensions of the tank and its place in the ship.

The following approach is used. The weight of the tank is estimated by multiplying the area of the tank by the thickness and the specific weight of the material. This weight is multiplied by an experience factor which is determined according to the weights of existing tanks. In case of a bi-lobe tank, the weight of the longitudinal bulkhead has to be added.
The thickness of the shell is not constant for each point of the tank. In the bottom the shell is thicker than in the upper part. In this stage of the design process it costs too much effort to calculate varying thicknesses. By using the experience factor, the effect of the difference in thickness is grossly eliminated. It is the order of magnitude of the thickness that is important.
In this approach, weight calculation is no more than an estimate. The weights of transverse web frames, stiffeners, piping and the tank dome should be added, but they are not determined in this section.

The thickness of the shell can be calculated according to the *"Code for the construction and equipment of ships carrying liquefied gases in bulk"'*, by I.M.O. and the '*"Rules for the Classification of steel Ships"* by Det Norske Veritas.

The tanks, together with their supports and other fixtures, should be designed taking into account proper combinations of the various loads:

a. Internal pressure;
b. External pressure, should be based on the difference between minimal internal pressure and maximum external pressure to which any portion of the tank may be subjected simultaneously;
c. Dynamic loads due to ship motions;
d. Thermal loads: cargo temperatures below -55 °C: consider transient thermal loads during cool down period; consider stationary thermal loads where design supporting arrangement and operating temperature may rise to significant thermal stresses;
e. Sloshing loads: when partial filling is contemplated;
f. Loads corresponding ship's deflection;
g. Tank and cargo weights with corresponding reactions;
h. Insulation weight;
i. Loads in way of towers and other attachments;
j. Vibrations.

The extent to which these loads should be considered depends on the type of tank. In the early stage of the design only the *internal pressure* and the *loads due to ship motions* will be considered.

15.4 Relation between tank dimensions and ship dimensions

15.4.1 Length

The length between perpendiculars of the ship consists of:

$$L_{pp} = L_{aft\ peak} + L_{engine\ room} + L_{cargo\ space} + L_{fore\ peak}$$

The length of the aft peak, engine room and fore peak can be determined statistically from data of the current fleet and from the Veritas rules:

$$L_{ap} + L_{er} = P_B \cdot \frac{18}{1000} + 20$$

where:
P_B = installed power in kW

$$0.05 * L_{pp} \leq L_{fp} \leq 0.08 * L_{pp}$$

(Source: D.N.V. Pt. 3 Ch. 1 Sec.3 A402)

Some ships have one or two deep tanks, next to the collision bulkhead or the engine room bulkhead in which ballast water and/or fuel oil is stored.

The length of the cargo space depends on the number, type and size of tanks. The length of the cargo space for one tank, consists of:

stiffeners + void space + insulation + tank + insulation + void space

The length of the cargo space is the sum of the length of the cargo spaces for each tank, plus the strut against the fore peak bulkhead.

- The height of the stiffener is normally 300 mm.;
- The void space between the tank insulation and the bulkhead, for inspection purposes, is minimally 300 mm. *(Source: I.M.O. Gas Carrier Code)*;
- The thickness of the insulation is normally 100 mm. to 300 mm.;

- The length of the longitudinal cylindrical tank and the bi-lobe tank is:
  - With torisphical ends: $L_t = l_t + 0.5*D_t$;
  - With hemispherical ends: $L_t = l_t + D_t$;

  The length of the transverse cylindrical tank in the longitudinal direction of the ship is: $L_t = D_t$;

where:

l_t = length of the part of the tank with a constant section
D_t = diameter of the tank, or the diameter of the lobes.

This means that for each tank type, tank dimensions and the installed power, the minimum length of the ship can be estimated.

15.4.2 Breadth

The breadth of the ship depends very much on the stability and the damage stability. The minimum breadth is determined by the *Rules in the Code of the Carriage of Liquefied Gases in Bulk*, by I.M.O. and by the cargo tank dimensions. For IIG/IIPG and IIIG ships, the minimum distance between the cargo tank and the side is 760 mm.
So the minimum breadth for the IIG/IIPG and IIG ships is:

- With longitudinal cylindrical tanks: $B_{min} = 2*0.76 + 2*t_i + D_t$;
- With transverse cylindrical tanks: $B_{min} = 2*0.76 + 2*t_i + l_t + 0.5*D_t$.

if a ship has a combination of two or more different tank types, the minimum breadth of the ship is the largest minimum breadth of the tanks.

Ships with longitudinal cylindrical tanks often have double sides of 1/5 (mainly IMO type I cargo) of the breadth of the ship. In that case the minimum breadth of the ship is:

$$B_{min} = (D_t + 2t_i) * \frac{5}{3}$$

15.4.3 Depth

The minimum depth is determined by the *Rules in the Code for the Carriage of Liquefied Gases in Bulk*', by I.M.O. and by the dimensions of the cargo tank. For IIG/IIPG and IIIG ships the minimum distance between the cargo tank and the base line is B/15 or 2 m., whichever is the smallest. The space between the tank and the deck, for inspection purposes, should be at least 450 mm. So the minimum depth for the IIG/IIPG and IIIG ships is:

$$D_{min} = \frac{B}{15} + 2*t_i + D_t + 0.45, \ or \ 2 + 2*t_i + D_t + 0.45$$

whichever is the smallest.

15.5 Design methods in the calculation model

This section briefly describes the most important design and estimation methods that are used in the design program.

15.5.1 Weight calculations

The weight of the ship consists of the following components, and estimates:

- Weight of the ship's hull
  $W_s = w_s*L_{pp}*B*D$;

- Weight of the machinery
  $W_m = w_m*P_b$;

- Weight of the tanks and insulation;

- Weight of the fuel:
  Weight of the fuel depends on the installed power and the range of the ship;

- Weight of the cargo:
  The maximum weight is determined by the multiplication of the total capacity of the cargo tanks by 0.98*0.97 (98% maximum filling level and 0.97 t/m^3 is the specific weigh of the heaviest cargo VCM);

- Rest weight:.
  The rest weight is estimated as 8% of the deadweight.

15.5.2 Power prediction

The installed power influences the costs and weight of the machinery and the fuel costs. In order to determine the installed power, the resistance of the ship must be estimated. The method of Holtrop and Mennen generally gives good results and can be used in a preliminary design stage.

The input used for the method is:

Length between perpendiculars:	L_{pp}
Breadth:	B
Midship draught:	T
Trim:	0
Moulded volume of displacement:	$L_{pp}*B*T*C_b$
Centre of Buoyancy forward of $L_{pp}/2$ (%):	$40*(C_b - 0.65)$
Waterplane area coefficient:	$(1.463 - 1.26*C_b)/(2.12-2*C_b)$
Midship section coefficient:	0.97
Wetted area hull:	

$$L_{wl} * (2t + B) * C_m^2 * (0.453 + 0.4425C_b - 0.2862C_m - 0.0034657B/T + 0.3696C_w$$

no bulb

Wetted area rudder:	$0.03*L_{pp}*T*(L_{pp}/(B*C_b*1.01)7.2)^{-\frac{1}{3}}$
Bulbous bow data:	No bulb
Bow thruster data:	No bow thruster
Gravity of water:	1.025 t/m^3
Kinematic viscosity of water:	1.366*10-6 m^2/s
Number of propellers:	1
Diameter of propeller(s):	0.55*T

15.5.3 Damage stability calculation

Damage stability is an important factor in the design of gas carriers. However, a damage calculation costs a lot of effort. In the preliminary stage of the design little data are available, for instance on the ship's hull form and the ship's centre of gravity, so an exact damage stability calculation is not even possible.
Still, the cargo tank configurations are influenced by the damage stability demands, so some attention must be paid to the damage stability of the design.

An approach is to make a simplified damage stability calculation. The following assumptions are used:

1. The damaged ship has no trim;
2. The cross section of the ship is rectangular;
3. Scribanti's formula can be used;
4. The other tanks are damaged, the damage hold space is flooded over the complete breadth of the ship;
5. The permeability μ of the holds is 0.95 *(Source: I.M.O. Gas Carrier Code)*

Further assumptions are about the vertical position of the centre of gravity KG. The weights and their centres of gravity are:

1. The centre of gravity of the ship's hull = Constant * D;
2. The centre of gravity of the machinery is = 4 m.;
3. The centre of gravity of the tanks and insulation = the height of the double bottom + the diameter of the tank/2;
4. The centre of gravity of the cargo = the height of the double bottom + the diameter of the tank/2;
5. The centre of gravity of the fuel = half of the height of the double bottom;
6. The centre of gravity of the rest weight = Constant * D.

The program makes damage stability calculations for each cargo hold damaged, and for type IIG ships with more than one cargo hold, also damage stability calculations for two adjacent cargo holds damaged.
The damage stability calculations made by the program cannot be compared with the real damage stability calculations necessary for the classification of the ship, they merely estimate the angle of heel and the resulting draught using the following (approximating) method.
If a cargo hold is damaged, the bi-lobe tanks and the transverse cylindrical tanks are assumed to be damaged. Where longitudinal cylindrical tanks are used and the ship has double sides of width B/5 (transverse damage extend), the tank is assumed intact. If the cargo hold with a longitudinal cylindrical tank does not have a double side, the cargo tank is assumed damaged.
If a cargo tank is damaged, the cargo is lost and the displacement of the ship (Δ) and the centre of gravity (KG) is calculated.
The method followed hereafter is the method of lost buoyancy: the draught of the damaged ship is estimated by:

$$T_0 = \frac{1}{1.025}\ \frac{\Delta}{(L_{pp} * B * C_b * 1.01) - (b * l * \mu * C_m)}$$ where, in case of:

- A longitudinal cylindrical tank with a double side: l = the length of the hold, or twice the longitudinal extend of damage whichever is less; b = B/5.
- A longitudinal cylindrical tank without a double side: l = the length of the hold; b = B.
- Two longitudinal cylindrical tanks: l = the length of the hold; b = B/2.
- Other tanks: l = the length of the hold and b = B.

The height of the centre of buoyancy is estimated with a formula by Posdunine:

$$KB = \frac{T_0}{1 + C_b/C_{wp}}$$

The metacentric height (GM) is estimated by calculating the moment of inertia of the damaged waterline:

$$BM = 1.025\,\frac{I_{t_0} - \mu * b * \frac{1}{12}\, l - \mu * a^2 * l * b}{\Delta} \quad \text{and GM = KB + BM - KG,}$$

where a is the distance between the centre of gravity of the damaged area of the waterline and the centre line of the ship. Here, the influence of the free surface is $\mu * a^2 * l * b$.

If GM is negative then angle $\phi = \arctan\sqrt{(-2GM/BM)}$

If GM is positive then $\phi = \arctan(1.025\,\frac{\mu * l * T_0 * b * C_m * b_2}{\Delta * GM})$

with $b_2 = a + \frac{\mu * a * b * l}{C_{wp} * L_{pp} * B - \mu * b * l}$

The eventual draught at the damaged side of the ship is:

$T_d = T_0 + \frac{1}{2} B * \tan\phi$ *(Source: J.A. Korteweg, 1984)*

This method does not claim to give perfect answers, in the preliminary phase of the design it is not necessary, nor desirable, to make a complete damage stability calculation.

The strong points of this method are:

1. The method is simple, flexible and fast. It is not necessary to feed the model with extensive (and unknown) data. It is possible to change an estimated value (for instance the KG, light ship weight or block coefficient) into a, for the designer, more acceptable value;

2. The method is more reliable than a pure statistical method, for instance the freeboard in relation to the breadth.

The weak points of this method are:

1. The method is an approximation, the ship' hull form is unknown and the weights, centre of gravity and centre of buoyancy etc. are estimated.

2. A type IIG ship with two tanks generally has a deeptank for fuel between the two cargo holds, the length of the deeptank is the longitudinal extent of damage. This way, the ship can survive with one bulkhead damaged. This arrangement is not implemented in the model.

3. The distance between a longitudinal cargo tank and the ship's hull can be B/5 (without a B/5 double hull) so that, in case of damage, the cargo tank is assumed intact. This arrangement is not implemented in the model.

4. The model only calculates one load condition (all tanks fully loaded with VCM). A complete damage stability calculation deals with all possible load conditions, for every possible type of cargo.

5. The model only calculates the end state of the damaged ship. A complete damage stability calculation calculates all intermediate states as well.

6. The method assumes that damaged tanks can be flooded completely. This is not necessarily the case with a damaged (conical) bi-lobe tank. The damaged lobe will easily be filled with water but the other lobe is partitioned off by the longitudinal bulkhead.

7. Trim is not calculated. In particular with the first cargo tank damaged, this makes a difference.

15.6 Costs of the cargo system, the building costs and the operational costs

15.6.1 Costs of the cargo system

The spherical tank is left out of consideration because normally it is not used on SP/FR ships, so there are no data available on the costs of spherical tanks for these ships.

The costs of a tank can be divided into the costs of the tank itself, and the insulation of the tank. The costs of the tank are linearly correlated with the weight of the tank. There is a difference in price between the ethylene tank (-104 °C, 5% nickel steel) and the normal tank (-48 °C).

The costs of the tank is calculated as a constant price per kg. The costs of the insulation depend on the insulated area and are calculated as a constant price per m^2.
Normally, the thickness of the insulation is 10 cm. for cargo temperatures down to -48°C, and 30 cm. for temperatures down to -104°C.

The costs of the cargo system are difficult to estimate. A fairly simple estimation, is that the costs of the cargo system are about 45 to 50 % of the total gas plant costs. This figure includes engineering work; it does not depend on the cargo tank configuration (number and type of the tanks and the design pressure). Based on a 6000 m^3 ship, in prices of 1989, this gives the figures shown in **Table III**.

Item	LPG (-48 °C)	Eth (-104 °C)
Total price (incl tanks)	12 - 14 milj DM	15 - 17 milj DM
Tanks + insulation	45- 50%	45- 50%
Reliquefaction plant	12- 14%	18- 20%
Pumps & heaters	6- 8%	5- 7%
Inert gas system	5- 6%	4- 6%
Cargo piping	14- 16%	13- 15%
Instruments & safety	6- 8%	6- 8%
Utilities (hydraulic, glycol, methanol, air system switchboard)	6- 8%	4- 5%
Of the total ship	33- 38%	35- 40%

All engineering, erection and materials included.

Table III: Costs of the cargo system

A weak point in this approximation is, of course, that the cargo tank configuration has no direct influence on the costs of the cargo system. For instance, if a lot of small cylindrical transverse cargo tanks are used, a lot of pumps are necessary which will raise the costs of the cargo system. This effect is not directly noticeable in this approximation. The number of segregated cargoes the ship can transport does not count either.

15.6.2 Building costs

The building costs can be divided into the costs of the ship and the costs of the machinery.

The building costs of the gas carrier are closely related to the weight of the ship. The yard uses the following relation for the price of the ship:

$$Costs_{ship} = C_1 * L * B * D + C_2 * L * B + C_3 * L * (B + D) + C_4$$

The costs of the machinery are closely related to the power of the engine(s). A simple estimation for these costs is:

$$Costs_{machinery} = C_5 * P_b \text{ where } P_b \text{ is the installed power in kW.}$$

15.6.3 Operational costs

The operational costs can be divided into fuel costs, running costs, purging costs, cleaning costs and port costs.

Fuel costs

The fuel costs depend on the fuel price and the fuel consumption of the ship. Because these ships trade worldwide and often in a pool or consortium, they do not trade on one specific route; therefore fuel is bought on different locations and at different prices. The newer vessels use the 380 cst oil, which can be used for both the main and the auxiliary engines. The prices of this oil vary considerably around the world and from day to day.

The fuel consumption depends on the size, the routes and the speed of the ship. The consumption can be divided into the consumption of the main engine(s) for propulsion of the ship, and the consumption of the auxiliaries for the reliquefaction plants and generators.
The fuel consumption of the main engine depends on the power of the engine and on its specific fuel consumption. In this type of ship, generally a medium speed four stroke engine is used. The specific fuel consumption of this type of engine is between 210 to 225 g/kWh (average 220 g/kWh). At a continuous service rating of the engine of 85% of the maximum continuous rating, the fuel consumption can be estimated as:

$$P_b * 0.85 * 0.22 * 10^{-3} * 24 = P_b * 4.5 * 10^{-3} \text{ tonnes per day.}$$

The fuel consumption for the auxiliaries is fairly constant. The average fuel consumption of the auxiliaries is estimated on 5 tons per day.
The daily fuel costs can be estimated as:

$$(P_b * 4.5 * 10^{-3} + 5) * \text{fuel price} \quad (P_b \text{ in kW})$$

Running costs

The running costs of gas carriers are fairly constant. The reason for this is that on these ships, because of the many port calls and the amount of work to be done, there is more crew than the rules minimally demand. The size of the crew does not change dramatically with the size of the ship. Maintenance costs do change a bit with the size, but not tremendously.
The overhead costs are the costs of the technical and commercial management of the ship.
The maintenance and repair costs are the costs of keeping the service level of the ship constant, the acquisition costs are the costs for upgrading the service level.
The casualty costs are the break down costs that are not covered by the insurance. The budget assumes two break downs per year.
Even the insurance costs are more or less independent of the size of the ship. The relative insurance costs (as a percentage of the value of the ship) of a 4000 m^3 gas carrier are approximately 1.5 times the relative insurance cost of a 12,000 m^3 gas carrier. However, because the larger ship has a higher value, in absolute terms the insurance costs are approximately the same.

Purging and cleaning costs

The purging and cleaning costs depend on the price of the fuel used for the inert gas generator, the price of the nitrogen used for purging the tanks, the quantity of inert gas and nitrogen used per cleaning and the number of times this takes place per year.
The price of the nitrogen is approximately US$0.40/$m^3$. The price of the inert gas from the ship's inert gas generator depends on the price of the fuel.
While approximately four times inerting and ventilating are needed when cleaning the tanks, the total quantity of inert gas is four times the tank capacity. Tank purging with nitrogen needs only be done once (after the tank has been cleaned).

Port costs

Port costs are estimated at US$10,000 per call. The number of calls per year varies from ship to ship. It strongly depends on the route the ship is used on.

15.7 Description of model *GASSHIP*

This section briefly describes the computer model *GASSHIP*. The principles of the design of a gas carrier have been described before.

In short, the design process is as follows:

1. Choose a cargo tank configuration;
2. 'Design' the tanks; calculate tank capacities, weights and insulated areas;
3. 'Design' the ship; the dimensions of the ship depend heavily on the dimensions of the cargo tanks;
4. Determine the capital costs and the operational costs of the ship.

This process is, of course, iterative. After the costs are determined and compared to the costs of other cargo tank configurations, the cargo tank configuration can be changed in step (1). Other sub-iterations are after step (2) back to step (1), and after step (3) back to step (1) or step (2). **Figure 14** is a general model description showing the four design steps.

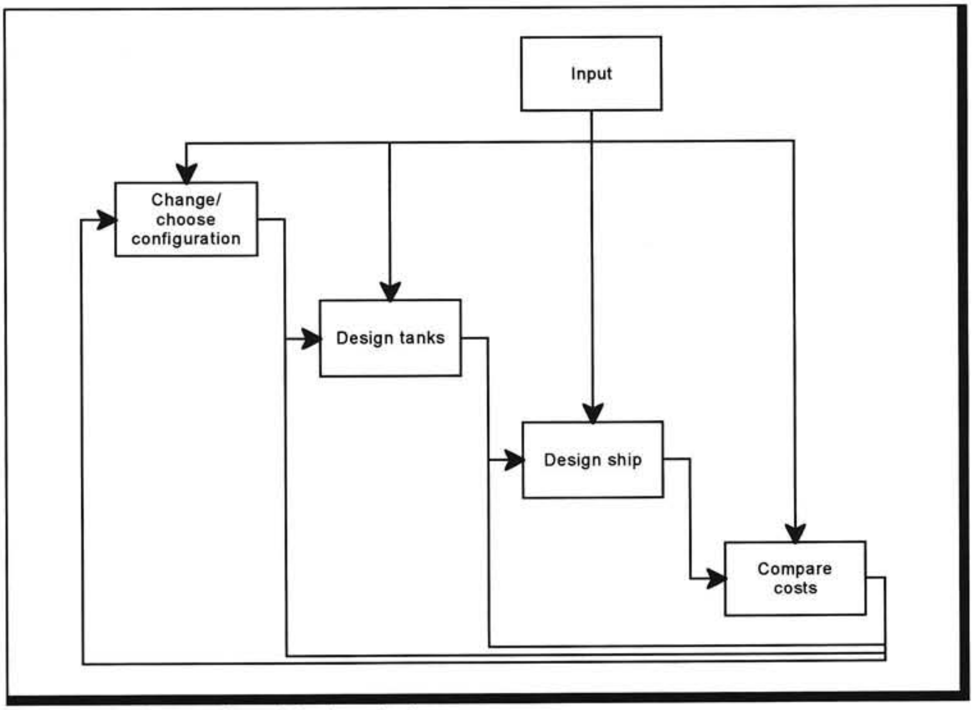


Figure 14: General model description

The following sections explain the structure of the program.

15.7.1 Menu structure

In the *main menu* the user can decide which step of the design process he wants to carry out. The menu contains the following options:

- Input;
- Configuration;
- Design Tanks;
- Design Ship;
- Calculate Costs;
- Print Results;
- Leave Program.

Input enables altering values of certain parameters and design results. *Configuration* serves to choose or change the cargo tank configuration. *Design Tanks* calculates the cargo tank capacities, weights and insulated areas. *Design Ship* calculates the ship dimensions, installed power and other ship parameters. Further a first damage stability calculation is performed and the ship design is evaluated by comparing the ships main dimensions with the total cargo tank capacities. The results of these calculations all appear on the screen. *Calculate Costs* calculates the capital costs and the operational costs of this design.

Main Input Menu

In the *Main Input menu* the user can alter values of specific parameters and design results. These input parameters are divided into five groups.

- Ship Dimensions;
- Ship Weight;
- Other Ship Specifications;
- Material Specifications;
- Cost Parameters.

Ship Dimensions Input

The following dimensions can be changed:

- Breadth;
- Depth;
- Length Machinery Room;
- Length Deep Tank;
- Length Fore Peak;
- Height Double Bottom.

Normally, these dimensions are determined by the program. The default dimensions are minimum dimensions, the ship is designed around the cargo tanks. The user is able to choose a fixed dimension for specific values.

Ship Weights Input

The following *ship weights* can be changed:

- Light Ship;
- Weight Fuel;
- Rest DWT;
- KG Light Ship;

These weights are determined by the program. The user can also choose fixed weights.

Other Ship Specifics Input

The following other ship specifics can be changed:

- Speed;
- Pressure;
- Block Coefficient;
- Power;
- Ethylene yes/no;
- Propeller Diameter.

Some of these specifics are determined by the program (pressure, block coefficient, installed power and the propeller diameter). Other specifics are user input-variables (speed, ability to transport ethylene (yes/no)). Again, the user is able to choose fixed values.

Material Specifics Input

The following material specifics can be changed:

- Nickel Steel;
- Low Temperature Carbon Steel;
- Insulation Thickness.

With *Nickel Steel* or *Low Temperature Carbon Steel* the user can change the yield stress and the tensile strength of these cargo tank materials.
With *Insulation Thickness* the user can change the thickness of the insulation of a cargo tank with cargo temperatures down to -104°C (ethylene), or a cargo tank with cargo temperatures down to -48°C (LPG).

These specifics all have default values at the start of the design process. Again, the user can choose fixed values.

Cost Parameters Input

The following cost parameters can be changed:

- Fuel price, US$/ton;
- Specific fuel consumption, g/kWh (default 185 g/kWh);
- Number of days per year (default 340);
- Number of voyages per year (default 30);
- Number of cargo changes per year;
- Endurance (default 30 days).

Configuration Menu

In this step of the design process, the cargo tank configuration is chosen. The cargo tank configuration is defined by the number of tanks and for each tank:

* The tank type. The user can choose from:
    1. Longitudinal cylindrical;
    2. Transverse cylindrical;
    3. Two longitudinal cylindrical;
    4. Bi-lobe;
    5. Conical bi-lobe.
* The dimensions;
* The types of ends used, the user can choose from:
    1. Hemispherical;
    2. Torispherical.

This *configuration menu* has the following possibilities to choose from:

- Number of Tanks;
- Tank Dimensions;
- Minimum Breadth & Depth;

If a longitudinal cylindrical tank is chosen, the program asks whether a side tank of the size B/5 is used, otherwise an a free space of 760mm. is used.

After the dimensions of all tanks have been entered, *Minimum Breadth & Depth* gives the user the possibility to check the minimum breadth and depth of the ship for this configuration without having to 'design' the tanks and the ship.

15.7.2 On screen information

The screen displays as much information as possible about the cargo tanks and the ship. Some information is displayed at every moment, some is displayed only after specific calculations. A typical screen may look as shown in **Figure 15**.

Nr	1	2*	3	4	5
Type	con lobe	transv	transv	transv	transv
l	9.000	16.600	16.600	16.600	16.600
D	11.400	11.400	11.400	11.400	11.400
z	5.200				
l_2	9.000				
D_2	11.400				
End1	hemi	tori	tori	tori	tori
End2	tori	tori	tori	tori	tori
Cap	2110.3	1489.6	1489.6	1489.6	1489.6
Wght	162.5	95.9	98.5	95.9	98.5
Area	810.7	591.4	591.4	591.4	591.4

Main Menu

Input	$^*L_{pp}$	107.072	C_{ap}	8068.6
Configuration	B_m	18.720	L_{er}	23.123
Design Tanks	D_m	13.698	L_{fp}	5.354
Design Ship	T	9.433	L_{dt}	7.516
Calculate Costs	$.C_b$	0.670	Eth	yes
Print Results	P_b	3263.7	H_{db}	1.248
Leave Program	V	15.00	KG	9.608
	$.P_o$	5.00	KG'	7.881
	D_p	6.131	C_{wp}	0.793
	W_{sm}	4231		
	DWT	8884		

Figure 15: Typical screen lay-out

The left column of the ship data gives the following information:

L_{pp}	Length between perpendiculars (m)
B_m	Breadth moulded (m)
D_m	Depth moulded (m)
T	Draught (m)
C_b	Block coefficient

P_b	Installed power (kW)
V	Speed (knots)
P_0	Pressure (bar)
D_p	Propeller diameter (m)
W_{sm}	Light ship weight (t)
DWT	Deadweight (t)
C_{ap}	Total cargo tank capacity (m^3)
L_{mr}	Length engine room (m)
L_{fp}	Length fore peak (m)
L_{dt}	Length deep tank (m)
Eth	Ethylene transportation yes or no
H_{db}	Height double bottom (m)
KG	Centre of gravity of light ship (m)
KG'	Centre of gravity of light ship plus deadweight (m)
C_{wp}	Water plane coefficient

The bottom left of the screen displays the main menu.

If for any specific a fixed value is chosen this is indicated on the screen by a small dot (.) on the left or on the right of the specific dimension. In this case, the block coefficient, the pressure and the length of the fore peak are fixed.
In the example, the dimensions of cargo tank 2 are changed as indicated by the asterisk. The ship dimensions should be calculated as well, as indicated by the other asterisk.

15.8 Evaluation of the model

This section gives a critical evaluation of the computer model. The evaluation is divided into two parts: the evaluation of the design principles and the evaluation of the model results (model validation).

15.8.1 Design principles evaluation

The most important design principle choice is whether to take the cargo tanks as starting point and design the ship around them, or to take the ship as starting point and try to fit in an optimal cargo tank configuration. The first approach has been used. The cargo tanks are the main productive and cost factor in this ship type. In practice, the shipowner and the cargo plant designer determine the cargo tank configuration and later a shipyard is asked to design a ship for these tanks.

The first design principle is to determine the minimum length, breadth and depth of the ship by using the cargo tank dimensions. This is the right approach because this type of ship generally has no deadweight problem but a volume problem. This means that the volume of the ship should be maximally used by the cargo

The second design principle followed in the model is taking the block coefficient as starting point, which determines the draught. The block coefficient should be systematically varied in order to find an optimal value. Another possibility is taking the (maximum) draught as starting point. The block coefficient is a good starting point because:

- The ship's resistance depends on it;
- The damage stability depends on it;
- There is a statistical relation between the ship's speed, length and block coefficient;
- The form of the ships hull depends on it, this means that it tells something about the possible tank sizes and forms in the difficult places, for instance against the collision bulkhead.

15.8.2 Model and calculations validation

The model uses a few approximations to estimate a number of values. Most methods have been described in the previous sections. This section gives an overview of the results of these approximations.

Three approximations concern the cargo tanks: their capacity, weight and insulated area. These calculations are required in order to determine the ship's capacity, the costs of the cargo tanks and the costs of the insulation.
Several of these calculations are made for existing ships. These calculations show the validity of the design method, and enables making corrections.

The calculations show that the estimated tank capacities are very much equal to the actual tank capacities; no correction is necessary.

The calculated tank weights and insulated areas vary more from the actual figures, and a correction is necessary. The difference between the calculated tank areas and the actual tank areas is quite remarkable, since the area of the tank is calculated the same way as the capacity; the relation between the diameter and the area of the cross section of the tank and between the circumference of the cross section is determined. Then, these areas and circumferences are integrated over the length of the tank. So, principally the same approach is used, however the capacity calculation shows much better results than the area calculation.
The calculated weight of the cargo tank depends on the area and on the shell thickness. As explained, the calculated area shows differences with the actual tank area. The calculated shell thickness seems to be correct. Because of lack of

information only one comparison could be made, but this comparison shows that both the calculated and the actual thickness are 18.3 mm.
Important for the cargo tank weight calculation is the weights of the other tank components. These are uncertain.
On the basis of a statistical comparison between calculated areas and weights, and actual areas, weights correction factors are calculated by comparing the estimated areas and weights with the actual areas and weights.

A second calculation method used in the computer model is a power prediction method. This is used to determine the length, the weight and the costs of the engine room, and the fuel consumption of the ship.
The method used is the method by Holtrop and Mennen. For some ships the calculated power differs considerably from the actual installed power. The results of more than half of the power predictions are within a 6% margin, the others except one are in a 10% margin, the last one has a 26% difference!
The differences between the calculated and actual ship's power can be explained as follows:

1. Inaccuracy of the power calculation method by Holtrop and Mennen.
2. The computer program estimates the diameter of the propeller as a fixed percentage of the ship's summer draught.
3. The computer program uses a fixed (15%) margin between continuous service rating and maximum continuous rating, and a 5% sea margin;
4. The model does not use a shaft generator while some ships do.

Finally, the damage stability. The damage stability calculations made by the program cannot be compared to the real damage stability calculations necessary for the classification of the ship, they merely estimate the angle of heel and the resulting draught an approximating method.

15.9 *Norgas Chief* cargo tank configuration optimisation

15.9.1 Basis ship

The objective of this section is to find out which cargo tank configuration is optimal for a specific capacity. For this purpose, the *Norgas Chief*, a ship from the Norwegian Gas Carriers fleet, is chosen as an example. This ship has the capability to transport ethylene and the total cargo capacity is about 8000 m^3. **Table IV** contains the main data of the ship.
Several configurations are compared using the model *GASSHIP*. There are two ways of comparing: first a few different cargo tank configurations with the same breadth and depth of the ship are compared (**Figure 16**), then different

ship dimensions with the same cargo tank configuration are compared. All costs are based on 1989 prices.

Cargo tank data:

Nr	1	2	3	4
Type	bi-lobe	transv	bi-lobe	transv
l	17.750	16.600	19.000	16.600
D	11.400	11.400	11.400	11.400
z	5.200		5.200	
l_2				
D_2				
End1	hemi	tori	tori	tori
End2	tori	tori	tori	tori
Cap	2352.6	1489.6	2738.2	1489.6
Wght	268.8	96.5	316.5	96.5
Area	886.8	591.4	900.2	591.4

Ship data:

L_{pp}	102.011	C_{ap}	8070.0
B_m	18.720	L_{mr}	24.220
D_m	13.698	L_{fp}	5.101
T	9.661	L_{dt}	7.277
.C_b	0.700	Eth	yes
P_b	6170.8	H_{db}	1.248
V	15.00	KG	9.385
P_0	5.00	C_{wp}	0.807
D_p	6.280		
W_{sm}	4370		
DWT	9000		

total costs: US$ 27.71 million
operational costs: US$ 241,000 per month

Table IV: Standard ship configuration

All model input values (specific fuel consumption, number of voyages per year, material characteristics etc.) are kept default, except for the block coefficient. The block coefficient cannot be too small in order to avoid problems fitting the tanks using proper distances to the ship's hull. The speed of the ship (15 knots) probably is relative high, so the model suggests a block coefficient of about 0.65. In the following designs, the minimum block coefficient is kept 0.7.

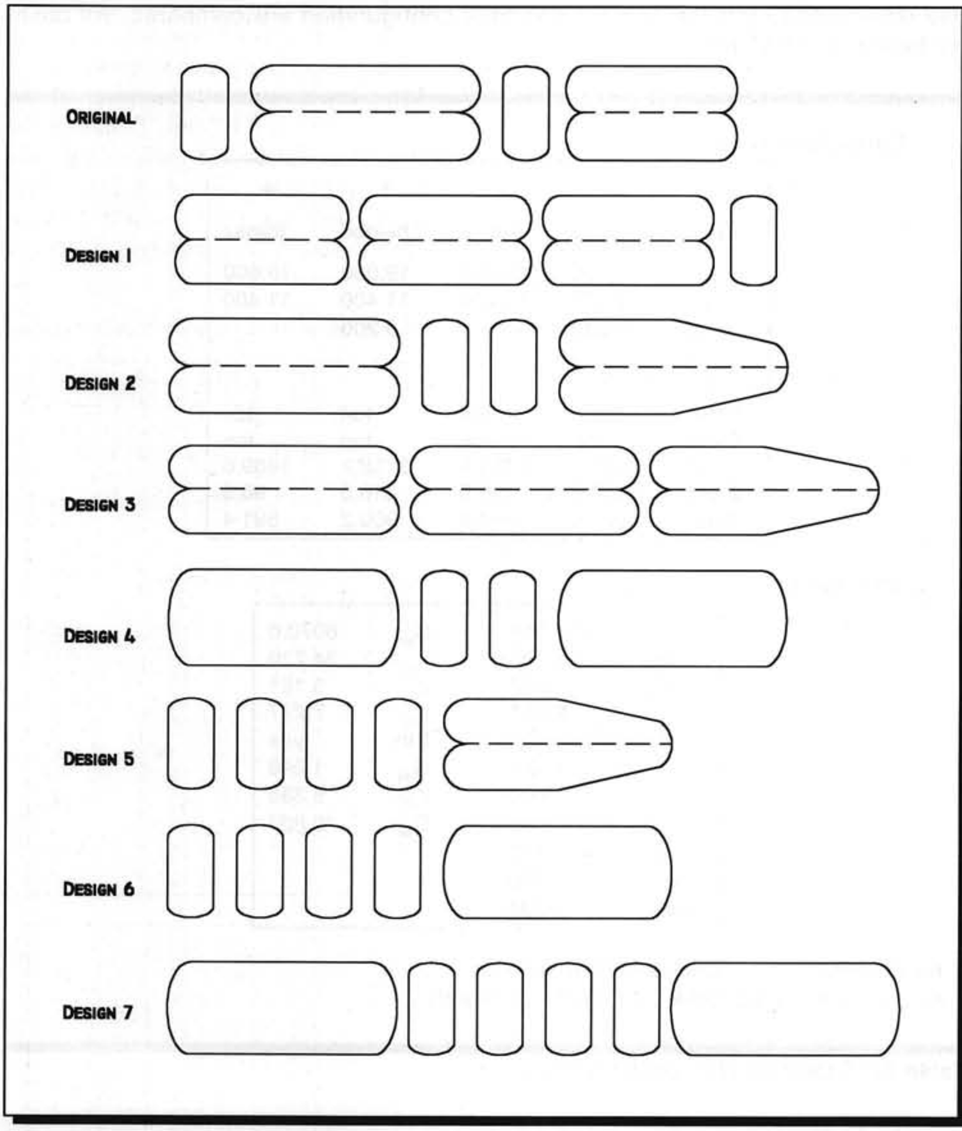


Figure 16: Design options

Configurations with a constant breadth and depth

Several different cargo tank configurations are examined, the results are compared to the *standard ship*. The actual configuration uses two bi-lobe tanks and two transverse cylindrical tanks. The bi-lobe tanks are complicated, expensive

tanks; the cylindrical tanks are less complicated and cheaper. A few configurations with complicated tanks (that have a better utilisation of the ship's space) and a few configurations with cheaper, less complicated tanks are examined.
Because the depth has a fixed value of 13.70m., the maximum diameter of the cargo tanks, except of the longitudinal cylindrical tanks, is 11.50m. Because the breadth is fixed on 18.72, the maximum length of a transverse cylindrical tank is 16.60m. and the distance between the lobe of a bi-lobe tank is 5.20m. This means that, keeping the same breadth and depth, only the tank lengths l and l_2 can be changed, the tank diameters D, D_2 and distance z are fixed. **Table V** shows the results of the calculations.

Option	1	2	3	4	5	6	7
L_{pp}	101.72	103.98	101.03	105.13	107.69	106.6	116.13
B_m	18.72	18.72	18.72	20.4	18.72	18.72	18.72
D_m	13.70	13.70	13.70	13.81	13.80	13.70	13.70
T	9.73	9.42	9.58	8.80	9.05	9.158	9.16
C_b	0.70	0.70	0.72	0.70	0.70	0.70	0.70
P_b	6213.0	5985.3	6.845.6	6249.6	5697.2	5776.9	5574.8
V	15.00	15.00	15.00	15.00	15.00	15.00	15.00
P_0	5.00	5.00	5.00	5.06	5.00	5.00	5.00
W_{sm}	6.32	6.12	6.22		5.88	5.95	5.82
DWT	4437	4311	4416	4658	4279	4291	4444
C_{ap}	8996	8982	9084	9013	8941	8952	8926
L_{mr}	8060.7	8074.5	8071.9	8073.5	8068.6	8070	8069.0
L_{fp}	24.27	24.00	25.01	24.31	23.67	23.76	25.52
L_{dt}	5.09	5.20	5.05	5.26	5.38	5.33	5.507
Eth	7.26	7.37	7.23	7.43	7.55	7.49	7.66
KG	yes	yes	yes	yes	yes	yes	yes
C_{wp}	1.25	1.25	1.25	1.36	1.25	1.25	1.25
	9.35	9.46	9.31	9.73	9.57	9.604	9.61
	0.81	0.81	0.81	0.81	0.81	0.807	0.81

	Bi-lobes	Lngitudina l.cylinders	Transverse cylinders	Investment Costs (US$ mln)	Operational Costs (US$ * 1000) per month	Cap/LBD
standard	2		2	27.71	241	0.309
design 1	3		1	28.86	242	0.309
design 2	2		2	26.62	240	0.302
design 3	3			29.15	246	0.312
design 4		2	2	26.82	242	0.273
design 5	1		5	24.81	238	0.292
design 6		1	5	24.72	238	0.295
design 7		2	3	25.62	237	0.286

Table V: Program results

Block coefficient variation

The design with a cargo tank configuration consisting of four transverse cylindrical plus a conical bi-lobe tank, design 5, has a block coefficient of 0.7. In this paragraph, the block coefficient is varied. The target is to find out the influence of the block coefficient on the ship dimensions and on the costs of the ship.
The results of the block coefficient variation are given in **Table VI**.

C_b	L_{pp}	T	P_b	Investment costs	Operational costs
0.64	106.62	9.86	4895	23.84	232
0.65	106.76	9.71	4995	24.14	233
0.66	106.91	9.57	5010	24.25	234
0.67	107.07	9.43	5235	24.37	235
0.675	107.16	9.37	5300	24.43	235
0.68	107.26	9.30	5370	24.50	236
0.69	107.46	9.17	5525	24.64	237
0.70	107.69	9.05	5700	24.81	238
0.71	107.95	8.93	5890	24.99	239
0.72	108.24	8.82	6110	25.20	241
0.73	108.57	8.70	6360	25.44	243
0.74	108.97	8.60	6660	25.72	245

Costs in million US$ and operational costs in thousand US$ per month

Table VI: Results of the block coefficient variation

It is clear that the smaller the block coefficient, the cheaper the ship. This is mainly caused by the difference of the price of the machinery.
Because a cargo tank configuration with transverse cylindrical cargo tanks has good damage stability characteristics, even a C_b of 0.64 has sufficient damage stability.
The lower boundary of the block coefficient with this configuration is not determined by the damage stability demands, but by the ship's hull form. In the bow section of the ship, a conical bi-lobe tank is used. This form generally fits nicely into the narrow fore end. It is difficult to estimate whether the first cargo tank will fit into the ship for specific block coefficients, because in the preliminary design stage, no information about the ship's hull form is available.
Another restriction is the draught. If a design has a draught that is too large, another block coefficient is better, even if this creates a more expensive ship. On the other hand, in case of a draught that is too small, one might opt for a larger length or breadth.

If the block coefficient is 0.68 instead of 0.7, about US$300,000 is saved on the total price (ship, machinery and cargo tanks), and about US$2,000 per month on the operational costs.

***Norgas Chief* cargo tank optimisation results**

From the calculation results can be concluded that the design with four transverse cylindrical tanks plus a conical bi-lobe or a longitudinal cylindrical tank (designs 5 and 6) are the cheapest. This is not what one would expect because the utilisation of the ships space (in the last column cap/L*B*D) with cylindrical tanks is not good, in any case worse than for bi-lobe tanks.
A second conclusion is that generally a ship with low capital costs has low operational costs as well. Undoubtedly this is influenced by the power of the engine of the ship. **Table VII** shows the relative prices.

The main reason for the operational costs difference is the difference in fuel consumption. Design 3 has a block coefficient higher than 0.7, design 4 has a larger breadth, due to damage stability problems; this causes a high ship resistance.

	Ship	Tanks	Machinery	Total	Operational Costs	Power
Standard	0	0	0	0	0	6170 kW
Design 2	+	-	-	-	-	5985 kW
Design 3	-	+	++	+	++	6845 kW
Design 5	++	--	--	--	-	5700 kW

Table VII: Relative prices

So, the conclusion is that sometimes it is better to have cheap cargo tanks in a large (expensive) ship with a low resistance than a small (and cheaper) ship with expensive cargo tanks and a high resistance.

15.9.2 Configurations with different ship dimensions

In the previous section, the most promising cargo tank configuration is the configuration with four transverse cylindrical cargo tanks plus a conical bi-lobe tank or a longitudinal cylindrical tank. The variation of the block coefficient showed the influence of the ship's form on the capital and operational costs.
In this section, the cargo tank configurations of design 5 and design 6 will be recalculated for variations of the cargo tank and ship dimensions. This can be

done by varying the cargo tank diameter, and for each diameter by varying the breadth of the ship.

The configurations with tank diameters 11.00 and 11.40m. have four transverse cylindrical plus a conical bi-lobe tank, the configurations with tank diameter 12.00m. have four transverse cylindrical plus a longitudinal cylindrical tank, the latter with a tank diameter of 13.00m. Using a tank diameter of 12.00m., a conical bi-lobe tank would have a distance between the lobe centres *z* of 3.88m. to 4.78m. that means *z*/D ratios between 0.32 and 0.4. These are low values, normally the *z*/D ratio is about 0.5 to 0.7. So, in the case of a 12.00m. tank diameter it is better to use a longitudinal cylindrical tank in the fore end of the ship.
Where conical bi-lobe tanks are used, the length of the conical part and of the straight part are kept about equal. The forward end of the first cargo tank is hemispherical, the other ends of all tanks are torispherical.
Furthermore, the minimum breadth and depth is used, and the block coefficient is kept at the value suggested by the program. The first cargo tank has a narrow forward end (conical bi-lobe or cylindrical tank) so there should not be any problems fitting the tank into the ship's hull with a block coefficient of about 0.68. The results are shown in **Table VIII**.

From the first optimisation around the optimal configuration was a ship with breadth of 18.72m., using cargo tanks with a 11.40m. diameter. The total costs were US$24.44 million, the operational costs were US$235,100 per month. By varying the cargo tank diameter and the ships breadth, the total costs are estimated at US$24,25 million, the operational costs at US$234,300 per month for a ship with 11.00m. diameter cargo tanks and a breadth of 18.00m. This is a difference of 0.8% in the total costs and almost 0.4% in the operational costs.
Generally, the ship with the smallest breadth is the cheapest. The breadth is limited by the minimum required damage stability of the ship. An example is a cargo tank diameter of 12.00m., a ship with a breadth of 18.00m. does not have enough stability when damaged.
A second conclusion is that there is an optimal cargo tank diameter for a specific cargo tank arrangement. In this case, the optimal diameter would be about 11.00m. The actual cargo tank diameter of the ship is 11.40m.
On the other hand, the differences in capital and operational costs are so small (less than 1%) which is smaller than the accuracy of the model, that one must be very careful to draw this conclusion.

Diameter = 10.50 m.

B	L_{pp}	D	T	C_b	P_b		Costs	Op.C.
18.00	114.800	12.750	8.666	0.700	5150		24.29	234.1
18.50	112.653	12.783	8.701	0.694	5245		24.46	234.8
18.72	112.406	12.789	8.657	0.693	5280		24.56	235.1
18.90	111.063	12.810	8.741	0.688	5295		24.58	235.2

Costs in million US$ and Operational costs in thousant US$ per month.

Diameter = 11.00 m.

B	L_{pp}	D	T	C_b	P_b		Costs	Op.C.
18.00	111.983	13.250	9.032	0.691	5165		24.25	234.3
18.50	110.051	13.283	9.056	0.685	5250		24.42	234.9
18.72	109.240	13.298	9.074	0.682	5280		24.50	235.1
18.90	108.598	13.310	9.081	0.680	5315		24.56	235.3

Costs in million US$ and Operational costs in thousant US$ per month.

Diameter 11.40 m. (actual value of ship)

B	L_{pp}	D	T	C_b	P_b		Costs	Op.C.
18.00	110.422	13.650	9.263	0.686	5190		24.29	234.4
18.50	108.120	13.683	9.328	0.679	5280		24.39	235.0
18.60	107.710	13.690	9.348	0.677	5285		24.42	235.1
18.72	107.180	13.698	9.353	0.676	5315		24.44	235.3
18.80	106.911	13.703	9.358	0.675	5325		24.47	235.4
18.90	106.592	13.710	9.360	0.674	5340		24.51	235.5

Costs in million US$ and Operational costs in thousant US$ per month.

Diameter = 12.00 m.

B	L_{pp}	D	T	C_b	P_b		Costs	Op.C.
18.00	-	-	-	-	-		-	-
18.50	107.040	14.283	9.574	0.675	5310		24.44	235.3
18.72	106.227	14.298	9.592	0.672	5340		24.50	235.5
18.90	105.574	14.310	9.601	0.670	5370		24.55	235.7

Costs in million US$ and Operational costs in thousant US$ per month.
-) breadth not possible due to damage stability demands

Table VIII: Results of the second optimation

15.10 Conclusions

General conclusions

The goal of the model has been achieved. With the model *GASSHIP* it is possible to calculate the costs of different cargo tank configurations, and to make sensitivity analyses for certain parameters. This can be done in a very short time so it is possible to calculate a great number of configurations.
The accuracy of the model calculations is satisfactory. In the preliminary ship design it is fairly impossible to achieve a very high accuracy (of about 1%). If in the model a structural mistake is made, or the estimates have a structural inaccuracy, this could result in an inaccuracy of all the designs that are compared. So, maybe the absolute figures are not within a 1% accuracy range, the overall tendencies are quite clear.

Conclusions from the model

Most surprising conclusion is that it is not always best to utilise the ship's available space as much as possible. Compared to bi-lobe tanks, cylindrical tanks use the ship's space poorly. In the case of the example ship it is better to have cheap cargo tanks and an expensive ship then the other way around. However, each design should be examined independently.

The block coefficient and draught are very important parameters. Firstly, for the resistance of the ship, a high block coefficient results in a high ship resistance which results in an expensive ship.
The block coefficient has a lower boundary caused by the damage stability of the ship. A large C_{wp}, and therefore a large block coefficient, gives a large distance between the centre of buoyancy and the metacentre (BM), with good (damage) stability characteristics as a result. Damage stability is also influenced by the freeboard and the tank configuration.
Secondly, the block coefficient has a lower boundary caused by a possible draught restriction.
Thirdly, the block coefficient has a lower boundary caused by the ship's hull form. If the block coefficient is too small, it might not be impossible to fit in the cargo tanks properly in the ships hull.

The ship's resistance is an import factor. The installed power concerns about 20% of the capital costs and the fuel costs about 20% of the operational costs.

CHAPTER 16: SEA-RIVER HATCHLESS CONTAINER SHIP

Many goods are transported from the U.K. to the Continent and vice versa. Goods moved by inland barge have to be transshipped into larger vessels to cross the North Sea. This gives them a disadvantage in the competition with road transport that is very difficult to overcome. For example, on the route from the interior of the U.K. to the interior of the Continent, goods have to be transshipped twice in sea ports (first in the sea port in the U.K. and then in the sea port on the Continent). Transshipment cost for steel products are about 30% from the total transport costs, for fertilisers this is about 25%. If transshipment can be avoided, this will reduce the integral transport costs considerably.

In this chapter, two ship types are described that can transport their cargo directly from the U.K. to the interior on the Continent. These alternatives are the NorthSea-Rhine Express and the Split ship.

16.1 NorthSea-Rhine Express

This case-study is based on, a study that was carried out in 1985 and 1986. All prices and amounts are based on 1986 data.

16.1.1 Introduction

The NorthSea-Rhine Express is a sea-river ship that can operate between sea ports in the U.K. and inland ports along the Rhine up to southern Germany, without having to transship its cargo. The ship can operate on three different market segments (**Figure 1**):

- Feeder container transport between the U.K. and Rotterdam. Feeder containers have origin or destination in Rotterdam;
- Barge container transport between Rotterdam and Germany. Barge containers have origin or destination in Rotterdam or Germany;
- 'Through' transport of containers between the U.K. and Germany. Through containers have origin or destination in the U.K. or Germany.

At sea the capacity of the ship is 448 TEU. Due to draught restrictions the capacity of the ship on the Rhine is 284 TEU, but this can be increased by putting two standard push barges in front of the ship.

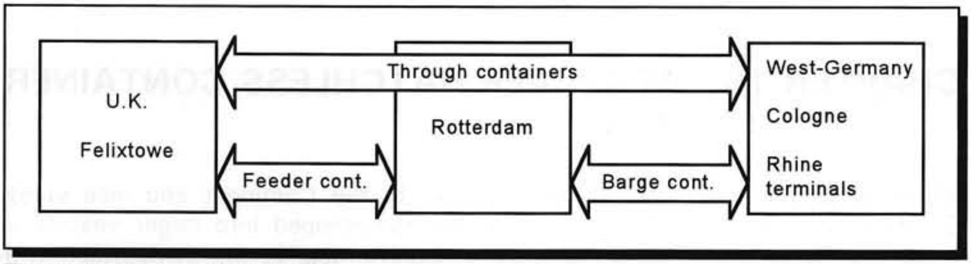


Figure 1: Market segments

16.1.2 Ship description

The general arrangement of the ship is given in **Figure 2**. The ship has the following characteristics:

▸ Length over all	109.80	m.
▸ Length perpendiculars	105.54	m.
▸ Breadth	18.20	m.
▸ Depth	10.20	m.
▸ Design draught (river)	3.00	m.
▸ Design draught (sea)	4.80	m.
▸ Air draught above base	12.80	m.
▸ Deadweight (river)	2,650	tonne
▸ Deadweight (sea)	5,850	tonne
▸ Trial speed	11	kn.

The ship is a low profile, twin screw diesel driven cellular open container ship. It has a cargo hold with 40ft. cells and is designed according to the highest class of Lloyd's Register of Shipping rules for specified area service at the assigned freeboard (LR + 100A1, + LMC, UMS, container vessel).
The cargo capacity of the ship is 448 TEU. The hold has a double bottom and side tanks. They are suitable for water ballast and fuel oil. The tank capacities are as follows:

▸ Bunkers	260	m^3
▸ Diesel oil	100	m^3
▸ Fresh water	90	m^3
▸ Lubrication oil	6	m^3
▸ Ballast capacity	2,650	m^3

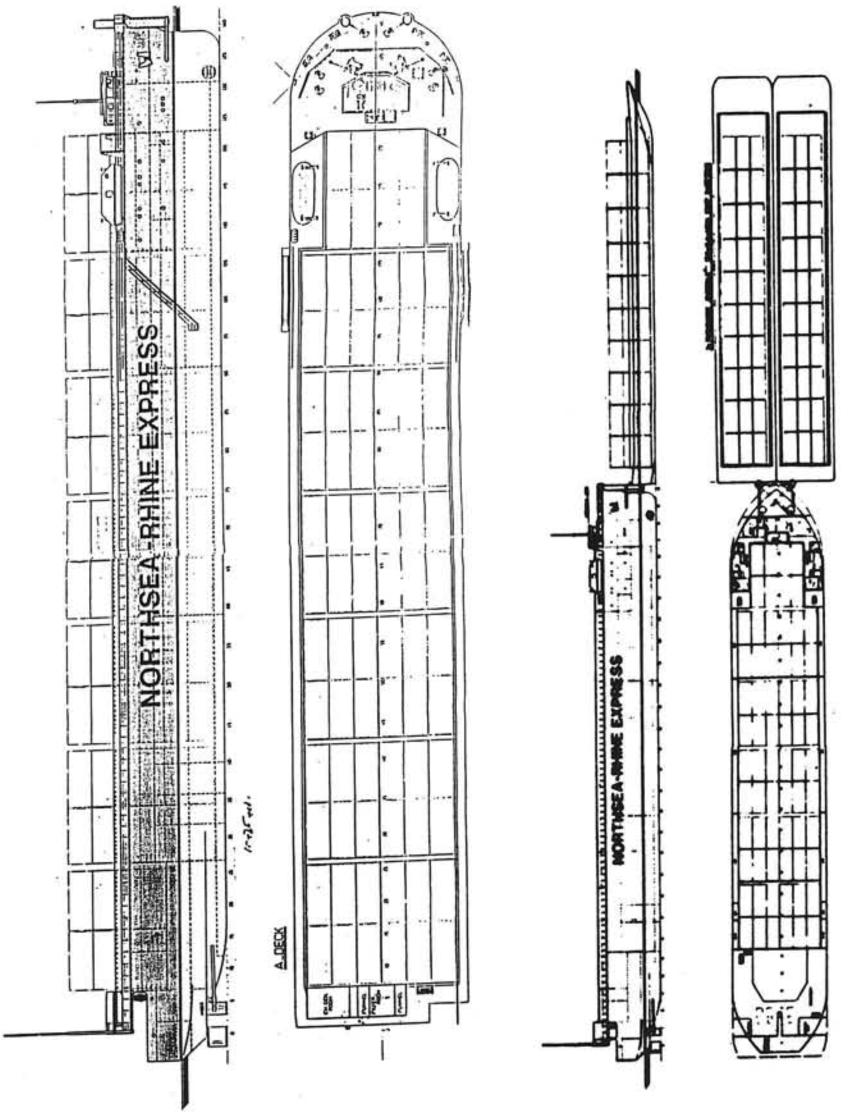


Figure 2: General arrangement of the NorthSea-Rhine Express

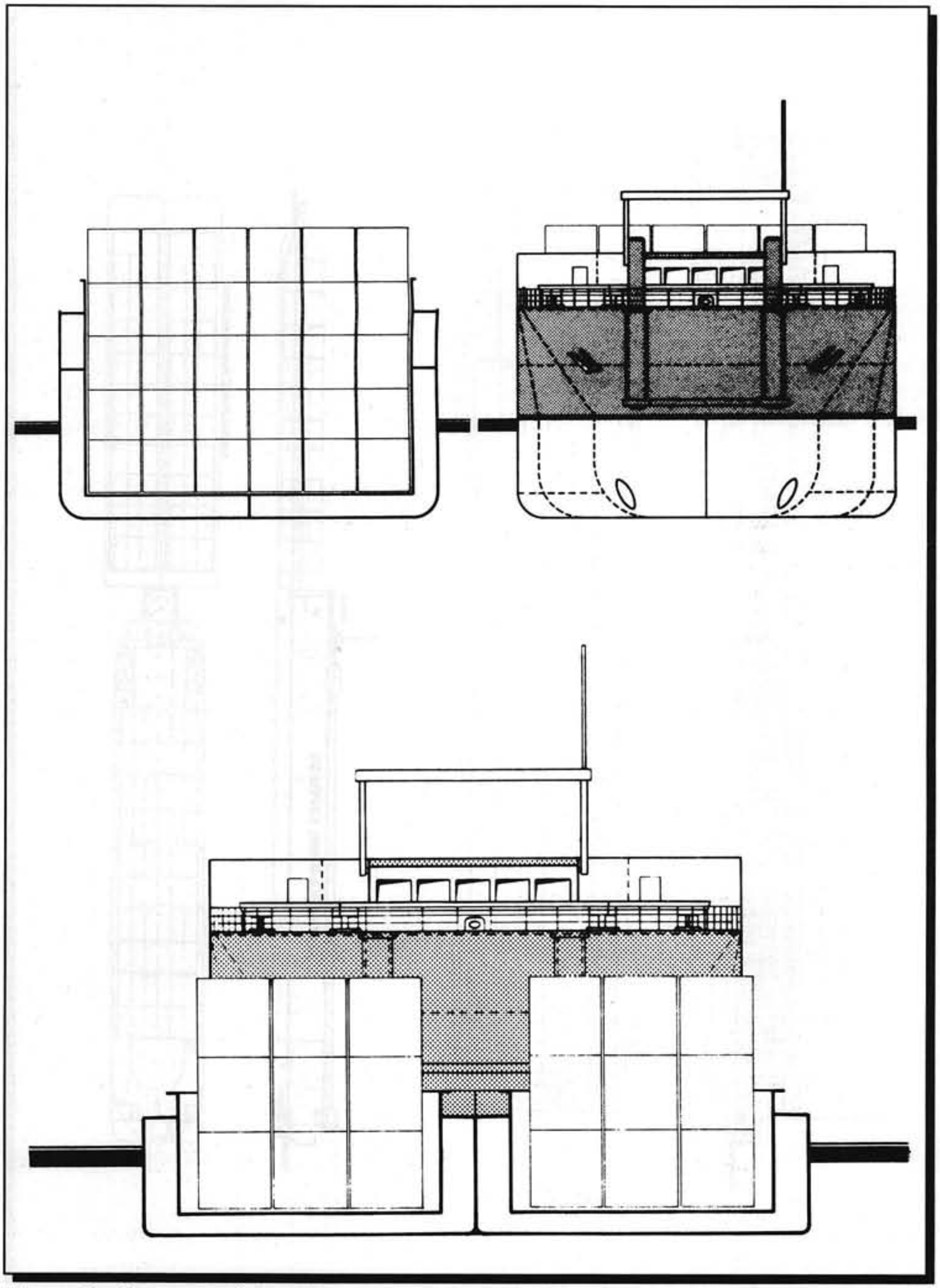


Figure 3: Cross-section

Two liftable pushing poles for push barges are fitted against the stem and enable the ship to push two push barges on the Rhine. A transom stern, two tunnels coming in from the sides, two nozzles and a skirt will allow for good shallow draught navigation. The minimum sailing draught, with a good flow of water through the nozzles, is about 2200 mm.

The main propulsion plant of the ship consists of two marine diesel engines, rated at 1200 kW. and 900 rpm, each suitable for driving a fixed pitch propeller, with a diameter of 2300 mm., via a reverse reduction gearbox and a line of shafting. The engines and reverse reduction gearboxes are controlled from the wheelhouse and locally. The layout of the engine room systems is suitable for unmanned operation. The ship has a bow propeller, driven by an electric engine, rated 400 kW.
Three diesel engines driven generators, each rated about 340 kW., are placed on the tweendeck level in the engine room. Two diesel engines, when running in parallel, can develop sufficient capacity for 30 reefer containers or the bow thruster as well as for other electrical consumers.

16.1.3 Economics

Service and market share

The NorthSea-Rhine Express service will consist of two identical ships. **Figure 4** illustrates the liner service between Felixtowe and Cologne. A round trip takes approximately 6.5 days, which results with two ships in service, in two per week from each port.

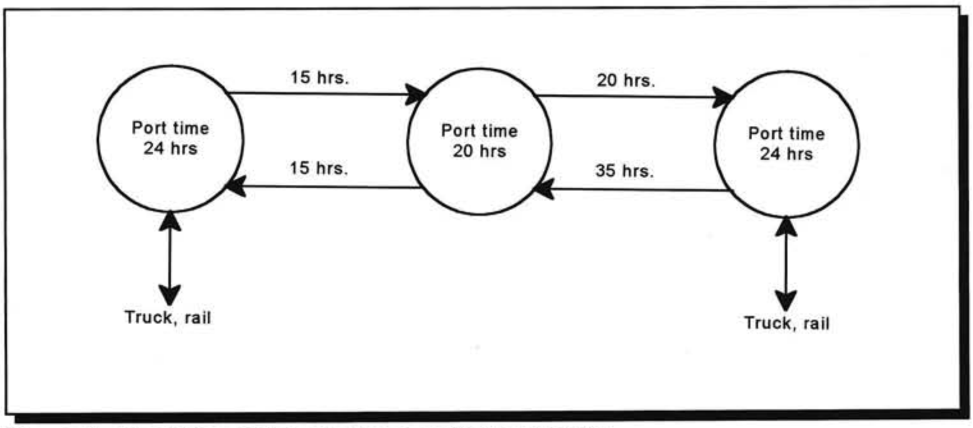


Figure 4: NorthSea-Rhine Express, sailing schedule

The capacity per year of the two ships is:

- Through containers 59,072 TEU (65% Utilisation = 38,396 TEU)
- Feeder containers 32,448 TEU (65% Utilisation = 21,091 TEU)
- Barge containers 37,440 TEU (65% Utilisation = 24,336 TEU)

The market share for the three segments should be judged against the development in time. Through containers and feeder containers will grow approximately 10 percent per year, which is a percentage based on the past years. Barge containers grow with 15 percent per year.
When the ships have a utilisation ratio 65 percent, they will have a market share of 27% for through containers, 8% for feeder containers and 10% for barge containers, compared to the expected volume in the year 1990.

Freight rates

The container transport market is very competitive, especially between the U.K. and the Continent. Major competitors are ferry operators. Presently approximately 75% of all unitised cargo is transported by trailer and 25% in containers.
The container sector is dominated by some door-to-door operators. These operators organise the entire transport in their own containers. The feeder containers are carried for the deep-sea lines, such as Sealand.
NorthSea-Rhine Express intends to work for those companies, where it provides a sealink between two ports and can, if necessary, get involved in door-to-door transportation (without owning/leasing the containers).

The pure freight rates for sea transport (so-called free in and out basis), which are very competitive are estimated on:

▸ Through containers	40ft	NLG 500.-
	20ft	NLG 365.-
▸ Feeder containers		NLG 115.- per TEU
▸ Barge containers[1]		NLG 50.- per TEU

Empty containers are 50% of the above rates.

Financial feasibility

The financial feasibility of the service is based on the following assumptions:

[1]The barge container rate reflects the net contribution margin after cost of renting the barge

- Investment - financing:
    - Investment in two ships is NLG 42 mln.;
    - Equity, 25% of the investment, is NLG 10.5 mln.;
    - IPZ premium 10.5% of investment is NLG 4.4 mln.;
    - WIR[2] premium 12.5% of (42 - 4.4) is NLG 4.7 mln.;
    - Mortgage (42 - 4.4 - 4.7 - 10.5) is NLG 22.5 mln.;
    - Interest rate 7.9%, grace period 1 year, load repayment over a period of 10 years.

- Operations - revenues:
    - Round trip time 6.5 days or 208 voyages per year (one way trip) with two ships;
    - Utilisation 65%;
    - Average mix between 20ft. and 40ft. containers is approximately 30-70% in TEU;
    - Average revenues are as described previously.

- Costs:
    - Linear depreciation over a period of 15 years or NLG 2.5 mln. per year;
    - Fuel cost NLG 1.4 mln. per year;
    - Crew cost NLG 2.8 mln. per year;
    - Insurance, maintenance and repair, survey NLG 1 mln. per year;
    - Port costs NLG 0.8 mln. per year;
    - Overhead NLG 2.0 mln. per year.

Figure 5 shows the financial feasibility and the internal (after tax) rate of return of the total project based on net cash flows. The internal rate of return after tax is 15%.

[2]The WIR and IPZ have been abolished since

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sales		15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000
Operational costs		6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
Interest		1858	1858	1654	1408	1232	1056	880	704	528	352	176	0	0	0
Depreciation		2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Overhead		2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
IBT		2642	2642	2846	3092	3268	3444	3620	3796	3972	4148	4324	4490	4490	4490
Tax (42%)		-1109	-1109	-1195	-1299	-1373	-1446	-1520	-1594	-1668	-142	-1816	-1886	-1886	-1886
Tax reduction		440	440	440	440	440	440	440	440	440	440	440	440	440	440
Net income		1973	1973	2091	2233	2335	2438	2540	2642	2744	2846	2948	3044	3044	3044
Operational cash flow		5142	4473	4677	4837	4909	5011	5114	5216	5318	5420	5522	5614	5614	5614
Debt repayment		0	2235	2235	2235	2235	2235	2235	2235	2235	2235	2235	0	0	0
Net cash flow		5142	2238	2442	2602	2674	2776	2879	2981	3083	3185	3287	5614	5614	5614
Equity -1100 - 500 - 2500															

Table I: Financial feasibility

16.2 Split ship

The split ship concept consists of two separate inland barges that both can move down the canal network on their own power. When the sea is reached, the two halves are connected to each other and the vessel can to continue its voyage on open sea. **Figure 5** shows the general arrangement of the vessel.
On completion of the North Sea crossing, the vessel splits again into two barges that both can sail down the Continental canal system. Nowhere in the journey, transshipment is required.

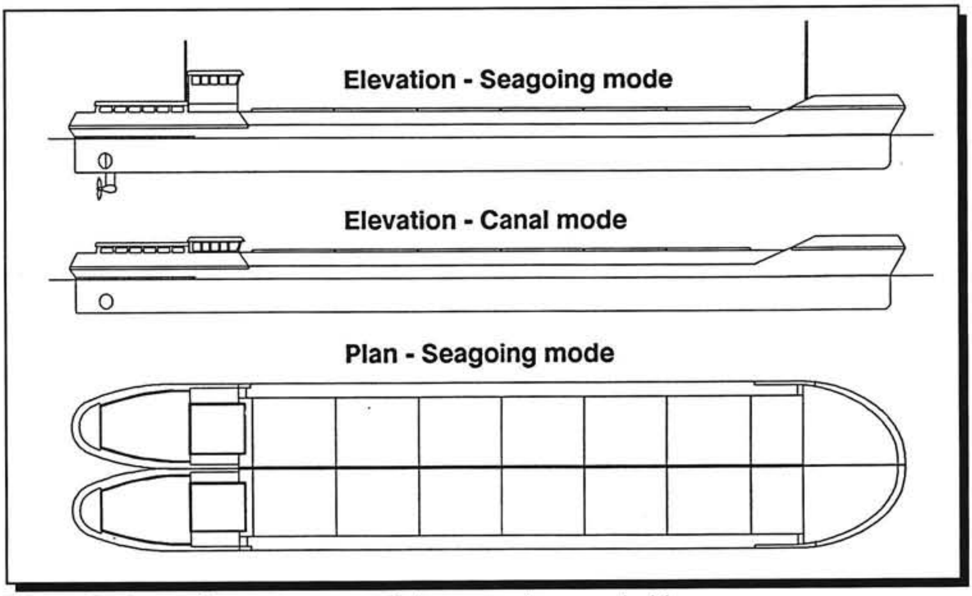


Figure 5: General arrangement of the seagoing canal ship

Two different ship types have been developed, a bulk cargo ship and a container ship. The bulk cargo vessel has an overall length of 60 m., a breadth of 6 m. and a depth of 3.4 m. The deadweight capacity of this vessel at sea (both halves together) is 1,100 tonne. Propulsion of the vessel is by means of two diesel engines, one for propulsion at sea driving a thruster unit, the other smaller one driving a pump jet for the main propulsion of each half barge in the canals.

The container vessel has the same overall dimensions as the bulk cargo ship, except for the depth, which is increased to 5.8 m. This causes a raise of the light ship weight and combined with the necessity for a larger ballast capacity, the deadweight of each barge is decreased to 440 tonne or 880 tonne for the

complete ship. This represents a load of 44 20ft containers of 20 tonne weight each.
The increased depth increases the ballast capacity and ensures that the vessel has sufficient stability. It also enables the vessel to pass the canal's bridges with limited air draught. The container ship is powered in the same way as the bulk cargo vessel. The cross sections of both ship types are shown in **Figure 6**.

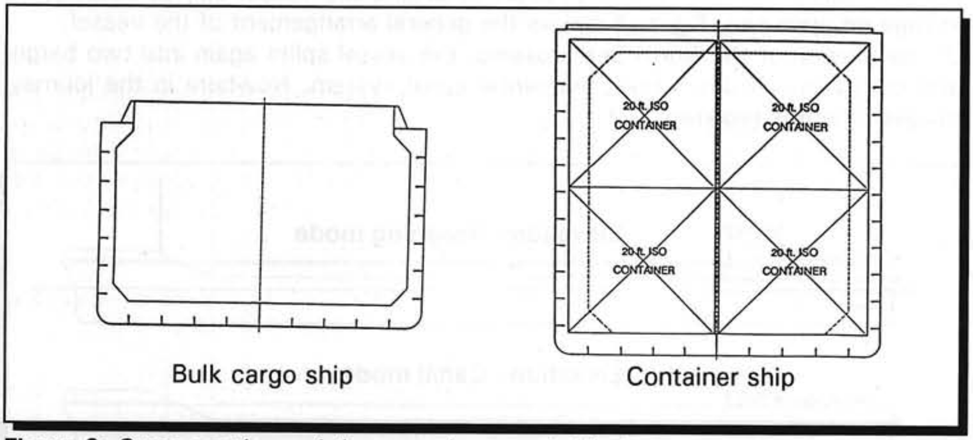


Figure 6: Cross sections of the seagoing canal ship types

In the U.K. the Yorkshire canal system is particularly suited for the concept of the split sea-river ships. Two of the canals in this system, the Aire and Calder, and the Sheffield and South Yorkshire have recently modernised locks, suitable for vessels carrying up to 700 tonne deadweight. The ship can also operate on the Manchester Ship Canal and the rivers Sever and Trent.
The canal system on the Continent is more suitable for the split sea-river ship than in the U.K, as the canals, rivers and locks are much larger. The ships are able to penetrate inland waterways as far as the upper reaches of the Seine in France, the Rhine, Elbe and Weser in Germany, and the Wista in Poland.

CHAPTER 17: SEA-RIVER TUG/BARGE CAR CARRIER

17.1 Introduction

This case-study concerns the design of a sea-river tug/barge system for car transport on the North Sea and Rhine, analogous to the common sea-river ship. On the Rhine the barge is pushed by a standard inland tug. At sea the barge is pushed by a seagoing tug equipped with a seaworthy coupling system. The advantage of this system is that the cars do not have to be transferred from an inland barge to a seagoing ship. Only the tug has to be changed.

The reasons for choosing a tug/barge system instead of a common sea-river ship are:

- The size of the crew depends only on the Gross Tonnage of the tug, not of the barge. Because of the light cargo (cars) the GT-value of the ship would be very high;
- At the Rhine only an inland crew (with lower rank) is required;
- The seagoing tug can fully take advantage of the unlimited draught, while the inland tug is especially designed for inland transport. This has a positive effect on the fuel consumption;
- The maximum length for ships on the Rhine is 110m., for tug/barge combinations this is 185m.

The system is designed to replace the present transport of cars manufactured in Germany and Belgium for the English market via Harwich. The car manufacturur produces its cars in three German factories: Rheine, Cologne and Saarlouis and one Belgian factory: Genk. The total number of cars transported by this manufacturer to England in 1991 was 140,800. This was the lowest number in years. On average, about 300,000 cars are transported.
Figure 1 shows the present and the alternative transport flows. *Presently* the cars are transported from *Genk* to Zeebrugge by truck, from Zeebrugge to Harwich by seagoing ship. From *Rheine* and *Saarlouis* the cars are transported to Cologne by truck, from *Cologne* to Vlissingen by barge, and from Vlissingen to Harwich by seagoing ship.
The *alternative route* for a tug/barge system is; from Genk, Saarlouis and Rheine to Cologne by truck. Transport from Cologne to Harwich by tug/barge system.

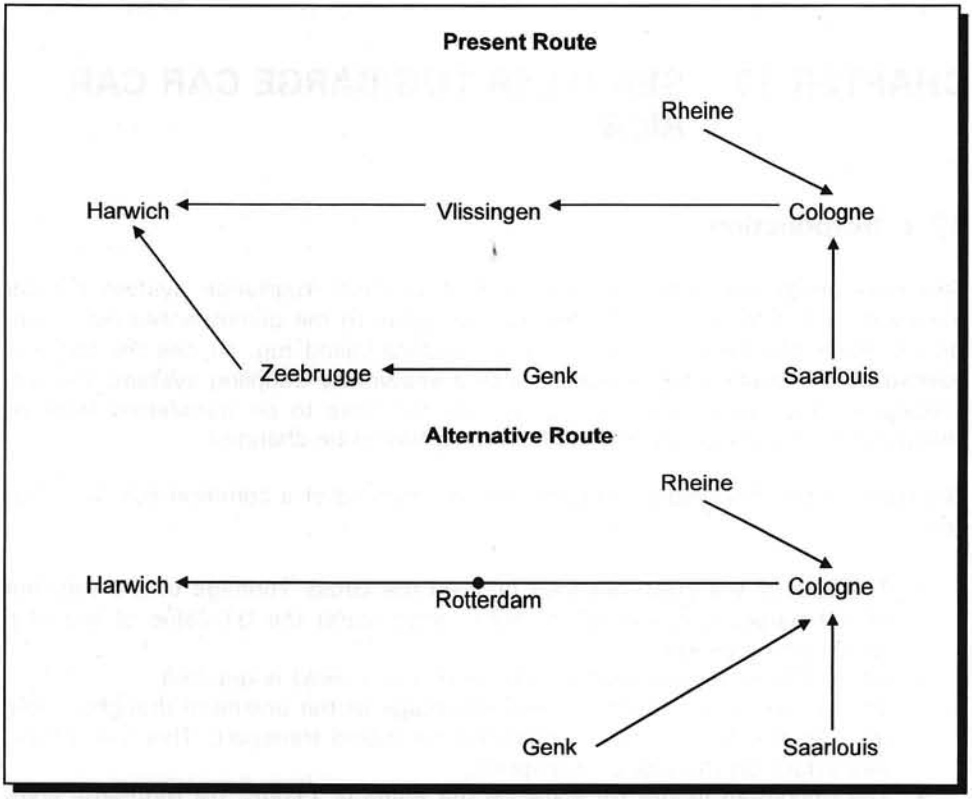


Figure 1: Present and alternative transport routes

17.2 Overview of tug/barge systems

This section gives an overview of tug/barge connection systems that can be used at sea.

17.2.1 Introduction

For many years barges towed by tugs have been a frequently used phenomenon. Especially in the United States, this method is used for coastal transportation, because of its flexibility, reduction of building costs, reduction of manning (mainly in the U.S.A.) and shallow draught.

A disadvantage of this method is the slow speed, due to the high resistance of the tug, the barge and the towing line. Because of the short length, the tug must operate at a relatively high speed/length ratio, which induces high wave-making resistance. The barge has a high resistance due to the skegs, required for good tracking characteristics.

When the tug is positioned behind the barge in a stern notch, the wave-making resistance becomes a function of the combined system. This, together with the absence of the skegs, reduces the total resistance.

In the first generation of tug/barge systems, the tug was connected to the barge by cables. In rough sea conditions, however, the system had to split up and the barge had to be towed again. The second generation barges had a deep notch at the stern. This increased the time the barge could be pushed at open sea.
The third generation tug/barge systems is designed with a rigid or non-rigid link system that permits the tug to push the barge almost 100% of the time.

17.2.2 Link systems

The tug/barge link systems can be divided into two main categories:

- Non-rigid systems;
  These systems allow various degrees of freedom between the tug and the barge. Most of these systems use a standard tug, fitted with a coupling mechanism. The resistance of these systems is somewhat higher than that of conventional ships of the same size. Non-rigid systems can be divided into:
  - Articulated connection systems;
  - Soft/wire connenction systems.

- Rigid-systems;
  Tug/barge units of this system have a connection that does not allow any relative movements of the tug to the barge. The two vessels act as a single unit and therefore the combination can sail in almost any seastate. Combinations of this system have almost the same resistance and fuel economy as conventional ships. Rigid systems can be divided into:
  - Dock-like notch systems;
  - Catamaran tug systems;
  - 3 point connection systems;

<u>**Articulated systems**</u>

Articulated systems connect the tug to the barge by a pin-connection or by a clamp. Some articulated systems are:

- Artubar;
- Articouple;

- Sealink;
- Bludworth.

The ***Artubar system*** was the first articulated system and patented in 1967. The tug is provided with steel hinge pins that enter a socket in the sides of the barge notch. The pin has a diameter from 1.2 to 2 metres. This connection allows the tug to rotate in a longitudinal plane about the pin axis. All other relative motions are prohibited. Disconnection of the tug and barge takes less than a minute, connection is possible within a few minutes. This system is able to sail in severe sea conditions. One of the existing units has survived hurricane conditions with wave heights up to 10.5 m.

Disadvantage of the Artubar system is that it does not allow different draughts of the tug and the barge. The ***Articouple system*** solves this problem. The initial F-type was developed for stone dumping barges. This system allows quick draught changes, without separating the tug and barge. The disadvantage is that oparation is limited to wave-heights of less than 3.5 m. The F-type has a pressing shoe, which is pushed into a groove (**Figure 2**). The H-type has a tooth shape pressing shoe and the groove is filled with teeth. Both sides fit into each other.

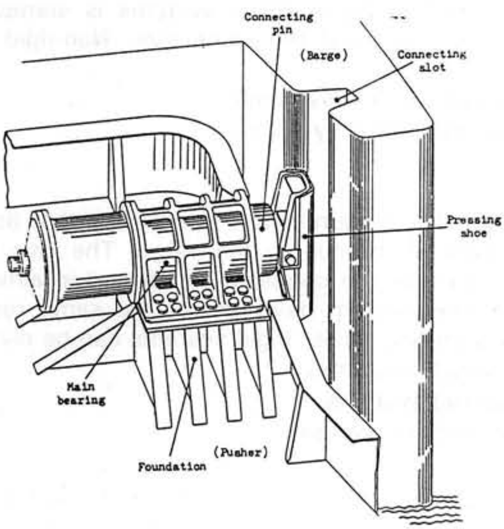


Figure 2: Articouple F-type

The ***Sealink system*** comprises a pushing frame, hinged about a transverse horizontal axis on the stern of the barge. Earlier Sealink designs permit the tug to heave, pitch and roll relative to the barge. Latter Sealink designs have a rigid frame so that roll of the tug is restrained (**Figure 3**).

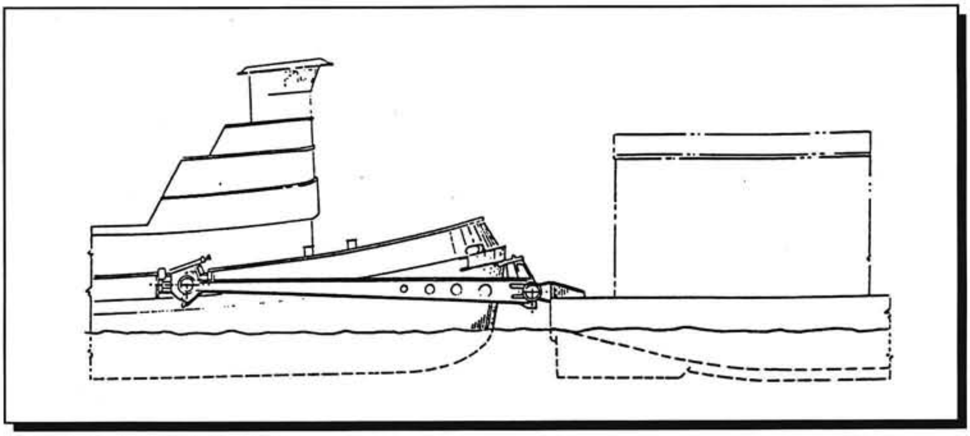


Figure 3: Sealink system

The ***Bludworth system*** holds the tug into the notch by a bow clamp on the tug that locks onto a vertical rail at the foot of the notch. The clamp is fitted with two hydraulic cylinders which push the cylindrical gripping members against the sides of the rail.
Lateral movements of the tug are restrained by a fixed pad at the port side and a hydraulic pad at the starboard side of the tug, which bear on vertical surfaces at the rear en of the notch.

Soft/wire systems

Soft/wire systems comprise the Seebeck and the Hydropad system. The ***Seebeck System*** uses a conventional tug and a straight sterned barge. The tug is fitted with a ball-type fender, which fits into vertical guidebars that are attached to the stern of the barge. Relative pitch and heave are allowed but damped, lateral movement is restricted by a tensioned line on each side of the tug.
The ***Hydropad system*** uses a deep notch in the barge, up to two third of the length of the tug. The tug is fitted with hydraulic pads on the sides, which expand and hold the tug and barge together. The pads are individually controlled and are made of steel-braced rubber. On the bow of the tug there is a roller so that it is free to heave and pich within the notch. The tug is held in its place by two tensioned wires, which are attached at either side of the barge's stern and at the tug's stern (**Figure 4**).

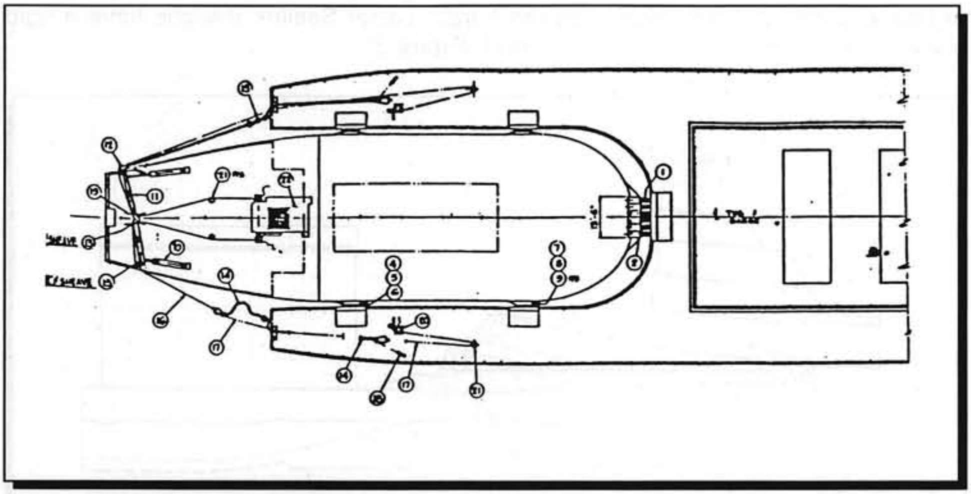


Figure 4: Hydropad system

Dock-like notch

Dock-like notch systems have a notch in the shape of the tug. The first system, constructed in 1951, was the ***Carport system***. The barge has a deep notch with a bottom floor and logitudinal structural overhangs at the main deck level of the barge. The tug has to be ballasted to be at the same draught as the barge and enters the barge dock on its own power. The final link is made by portable hydraulic jacks and secured by large turnbuckles at deck level (**Figure 5**). The other concepts, Seawedge and Breit-Ingram system, are basicly the same as the Carport system.

Catamaran tug

Catamaran tug systems comprise a catamaran shaped tug and an especially shaped barge stern that fits into the the two hulls of the catamaran. One of the catamaran systems, the ***Catug system***, locks the tug and barge together by two hydraulic tension latches on main deck level. All vertical and horizontal relative movements are restrained.
The longitudinal stability is a critical factor. Therefore connection and disconnection has to take place in a harbour and it is not possible to operate the tug separate from the barge. For the connection of the unit the barge has to be aligned exactly with the barge (**Figure 6**).

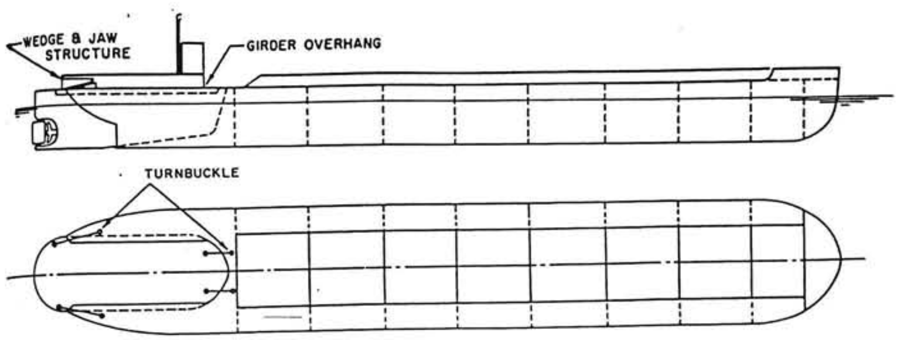


Figure 5: Carport system

Three point connection

These systems fixate the tug to the barge on three points, so the tug cannot move relative to the tug. One of the three point connection systems is the **Finnpusku system (Figure 7)**. The main characteristics of the connection system are the tapered shape of the pusher, a fixed front connection wedge and two hydraulically operated wedges, far aft on each side of the hull. In the barge, the connection sockets for these wedges are located at three levels, which makes it possible to connect the pusher to the barge at different draughts. The shape of the side wedges locks the pusher into the right position both sideways and in the fore and aft direction.

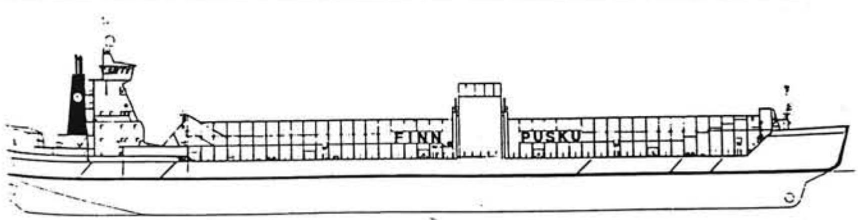


Figure 7: Finnpusku system

Three other three point connection systems are the Aoki, the Triofix and the Murvicker system.

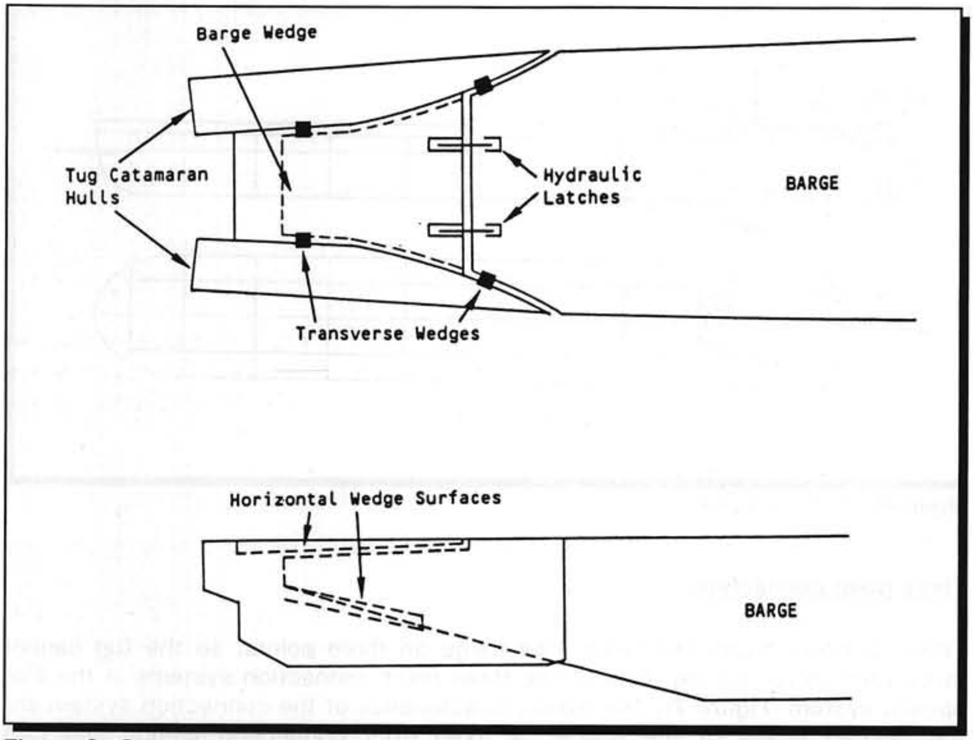


Figure 6: Catug system

17.3 Boundary conditions

General restrictions

Requirements of the car transport tug/barge system:

- At sea the barge has to be pushed by a conventional seagoing tug, equiped with a seaworthy coupling system;
- At the Rhine the barge has to be pushed by a standard tug;
- Easy loading and discharging;
- The barge must have the ability to manoeuvre without the tug (bow thruster);
- The capacity of the design is based on the export volume of 1991, which requires a transport volume of 2880 cars per week. If the car market recovers the export volume may increase. Then the number of barges has to be increased. Based on the volume of 1991 and a departure frequency

of 2.5 per week, only 2 barges are required, with a capacity of 1152 cars or more.

Sailing Area

Some restrictions that the Rhine puts on the barge design are:

- The maximum size of a tug/barge convoy on the Rhine is a length of 185.00m. and a breadth of 22.80m. With a maximum tug length of 40m. the maximum length of the barge is 145.00m.;
- The draught and the height of the barge must allow the barge to pass all bridges and to sail during low water periods. The maximum height above the water is 9.80m. the minimum draught is 2.50m. The maximum depth of the barge is 12.30m. (9.80 + 2.50).

Restrictions put on the design of the barge by the sea are:

- The barge has to meet all demands from the classification societies for seagoing ships;
- To prevent slamming, the minimum draught at sea is 0.025 * L. This means that sufficient ballast capacity is required.

Cargo restrictions

The nature of the cargo puts the following restrictions on the barge design:

- Height of the car decks is 1.65m., the height of the van deck is 2.34m.;
- Cars without mirror are placed 15cm. apart, cars with a mirror 30cm.;
- Maximum heel of the ramp is 10 degrees;
- The number of struts must be limited to the minimum, to avoid damage to cars.

Restrictions from the classification societies

Restrictions which are caused by the rules of the classifications societies are:

- Minimum height of the bow is 5.406m.;
- Minimum height of the tanktop is 1.050m.;
- Minimum length of the fore peak is 7.0m.

17.4 Description of the design

Dimensions
For the design the maximum allowed dimensions are chosen:

- Length over all 145.00m.;
- Breadth 22.80m.;
- Draught river 2.50m.;
- Draught sea 4.00m.; $(0.027 * L_{pp})$
- Depth 12.30m.;
- 5 car decks;
- Sufficient ballast capacity to obtain a draught of 4m. without cargo.

From five alternative cross sections, the cross section, shown in **Figure 8** was selected. A barge with this cross section has a transport capacity of 1226 cars, based on a specific set of car types, and a good damage stability. The barge has one deck on which vans can be loaded.
A barge of this form has a high metracentric height, which causes a short roll period. To decrease the GM-value the second ballast tank is placed at a high position. The general arrangement is shown in **Figure 9**.

Light ship weight and construction
Because existing methods for the estimation of the light ship weight are developed for motor ships instead of barges, the weight was estimated by calculating the thicknesses of the plates and the stiffeners and multiplying these by the areas and the specific steel weight. Other weights were estimated separately. This results in the following weights:

Steel weight	3638t.
Air pipes and ventilators	5t.
Equipment	72t.
Generator and pipes	15t.
Bow propeller	10t.
Diesel oil	8t.
Light ship weight incl. stores	3748t.

According to Lloyd's the section modulus of the cross section (**Figure 8**) is more than sufficient.

Ballast capacity
The required ballast capacity to obtain a draught (at sea) of 4 m., without any cargo loaded, is:

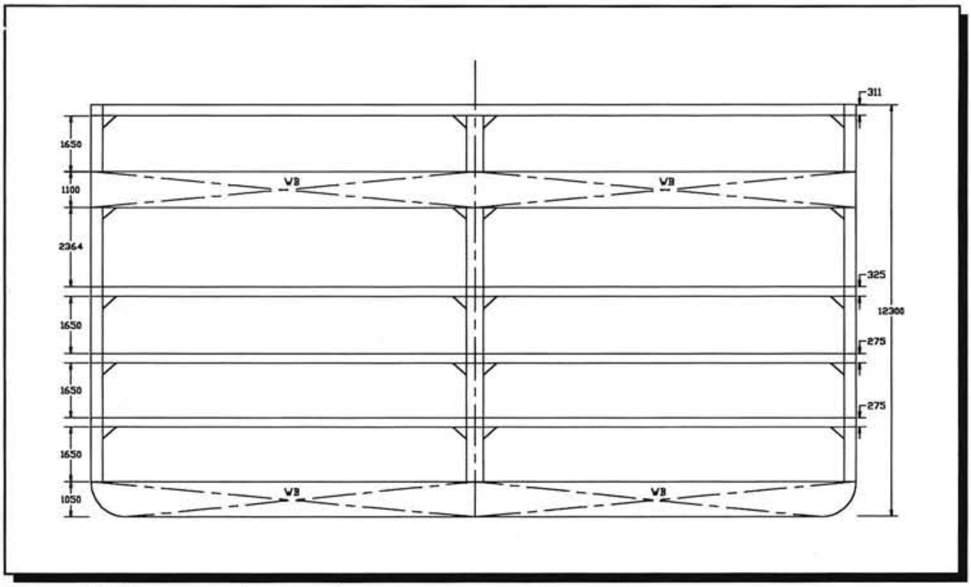


Figure 8: Cross section car barge

Displacement at 4m.:	9499	m^3
Required ship weight in sea water:	9737.5	tonne
Light ship weight barge:	3748.0	tonne
Required ballast capacity:	5989.5	tonne

The total ballast capacity of the barge is 5994.5 tonne, which shows that there is enough ballast capacity available.

Propulsion and auxiliary power

The required power for the seagoing tug is estimated by comparing the power of 33 existing tug/barge units with an articulated coupling. This comparison shows that the seagoing tug requires a power between 3000 and 5000 BHP.

On basis of this estimate a tug was selected with a power of 5420 BHP. 5 tugs in the range of 4250 to 15200 BHP on which sufficient data were available were selected and their admirality constant was calculated. With these data the admirality constant and required power of the tug was calculated, and a relation between the power and service speed was determined.

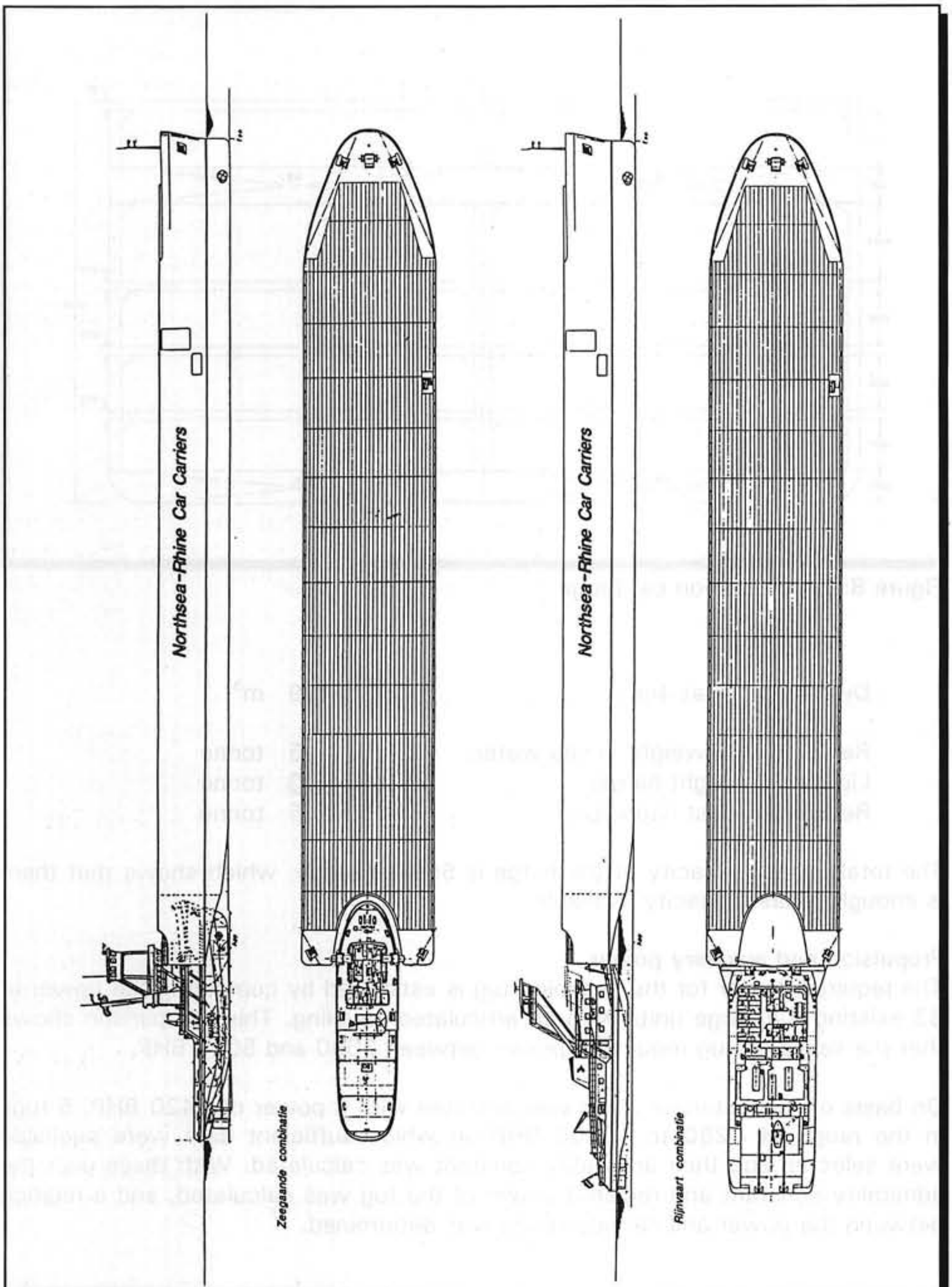


Figure 9: General arrangement barge

From this relation a speed of 12.8 knots was estimated. This is fast enough for the seagoing tug to make two roundtrips in the time that the inland tug makes one roundtrip.

The displacement of the barge at the Rhine is 5600 tonne (Draught is 2.50m.). To obtain a speed of 17km/hr in still water, approximately a power of 0.25 BHP per tonne is required (according to the regulations). This results in a power of 1400 BHP. The regulations also demand that if the combination sails with the current, the combination must have the ability to lay still. This means that the tug must be able to obtain a speed of 10km/hr in reverse. Therefore an extra power of 75% is required. The total required power is 2500 BHP.

The size of the auxiliary power is mainly determined by the bow propeller. The Instaled power is 1384 kVA.

Loading and discharging
Because the route of the barge is short it is important that loading and discharging happens very quickly. Several loading and unloading concepts have been developed of which one has been chosen. In this concept three ramps are placed ashore, two above each other and one adjacent. Their height can be adjusted.

Coupling system and conversions on the tugs
The following demands are put on the coupling system of the seagoing tug:

- It must be simple to convert the seagoing tug;
- The coupling has to function under any circumstances at the North Sea;
- Coupling must be quick;
- Short length of the notch.

On the basis of these demands there are two possible coupling systems: Articouple KD-type and Intercon. The Aricouple KD-type has been selected because already 40 tugs have been equiped with this system. Several combinations are already sailing 12 years with it, without any problems.
The seagoing tug requires a high steering house because of the view. It is not necessary that the height of this steering house can be adjusted.

The inland tug is coupled with the barge in the normal way, there are hardly any conversions required for coupling. The inland tug requires an adjustable (telescopic) steering house to ensure sufficient sight. The steering house must be adjustable because of the bridges on the route.

17.5 Economic evaluation

The port and sailing times are calculated based on the following starting points and assumptions:

- Distance between Cologne and Rotterdam is 318km. Sailing time Cologne-Rotterdam is 20 hours (speed 17 km/hr, 1 hour in lock). Sailing time Rotterdam-Cologne is 33 hours (speed 10 km/hr, 1 hour in lock);
- Distance between Rotterdam and Harwich is 128nm. Sailing time is 14 hours (speed 9.5kn., 0.5 hrs spare time), double trip;
- Port time in Cologne and Harwich is 12 hrs., port time in Rotterdam is 4 hrs.

The total transit time from Cologne to Harwich is 12 + 20 + 4 + 13 + 12 = 62 hrs. = 2.6 days

All costs, prices and tariffs are based on 1991 values.

17.5.1 Costs

<u>**Running costs**</u>

Both tugs are chartered instead of purchased. The charter rate of a seagoing tug of 5500 BHP is estimated between US$3500 and US$6000 per day. The charter rate of an inland tug of 2500 BHP is approximately NLG 4500/day. The other costs are estimated to be as follows:

▸ Insurance of the barges:	1% of the building price;
▸ Maintenance, repair and survey:	1.5% of the building price;
▸ Lubrication oil:	NLG 15,000 per barge per year.

<u>**Voyage costs**</u>

Fuel costs

Fuel costs depend on the trip. In the following calculations they are calculated separately for each alternative.

Port and pilot costs

The port costs in Rotterdam depend on the gross tonnage of both the barge and the tug. For a gross tonnage of 27,000m^3 the port costs are NLG 4646.- per call, for five or more calls there is a discount of 35%.
There were no data available on the port costs in Cologne. Therefore, the costs are estamed to be the same as in Rotterdam. In Harwich there are no port costs.

Ships that enter Rotterdam more than 20 times a year, do not require a pilot, the same goes for Harwich. So there are no pilot costs.

Capital costs

The building price of the barge is estimated as a fixed amount per kilogram light ship weight. For the barge a price of NLG 8.00 is estimated because of the relatively expensive bow thruster of the barge. The total price of the barge is NLG 30 mln.

Because the barge can only be used for car transport at the Rhine and at sea the economical life time of the barge is estimated at 15 years, and a residual value equal to scrap value.

The calculations are based on a loan during the entire period of the investment, with an interest rate of 8%. The repayment and interest are based on an annuity.

A normal seagoing tug requires some conversions and a coupling system has to be added. The costs for these conversions are NLG 1,440,000. Also the inland tug requires some minor conversion. The costs for these conversions are NLG 170,000.

The costs of the ramps, which are placed ashore, for loading and discharging of the cars, are NLG 788,000.

17.5.2 Economic calculations

The following economic evaluations have been made:

Option 1. Production volume of the car manufacturur in 1991: 140,800 cars per year;
Option 2. Usual production volume: 301,400 cars per year;
Option 3. Costs and revenues between 0 and 350,000 cars per year;

On the basis of 49 weeks per year and a barge capacity of 1185 cars, the number of sailings for *option 1* must be 2.5 per week. This means a departure every 67.2 hours. The roundtrips time of the inland tug must be less than 67.2, otherwise two tugs are required. The same goes for the seagoing tug. Because the roundtrip time of the barge is 113 hours (bigger than 67.2) two barges are required.

The revenues are estimated at DM 235 (NLG 258.50) per car which is equal to the present transport costs on the routes Zeebrugge-Harwich and Vlissingen-Harwich. Cost for truck transport is approximately the same as the present situation.

For *option 2* the same calculations have been carried out as for option 1. Now however, the number of sailings must be 5.5 per week. Therefore 4 barges, 2 seagoing and 3 inland tugs are required. The results of both options are given in **Table I.**

	Option 1	Option 2
Number of cars per year	140,800	301,400
Revenues (NLG*mln/year)	36,397	77,912
Costs (NLG*mln/year)	17,227	35,863
Number of barges	2	4
Number of seagoing tugs	1	2
Number of inland tugs	1	3
Min. required tariff (NLG/car)	122	119
Pay back period	3	3
Number of departures/week	2.42	5.19
Utilisation ratio (%)	97%	94%

Table I: Economic evaluation

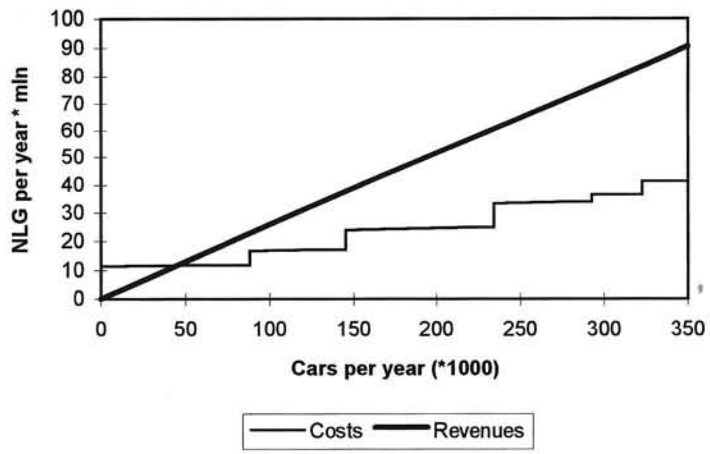


Figure 10: Revenues and costs as a function of the number of transported cars

Figure 10 shows the cost and revenues as function of the number of transported cars (*option 3*). The jumps in the costs are caused by an extra required tug or barge. The small increase in between is caused by the fuel costs and port costs. The break-even point for a freight rate of NLG 258.5 is 45,000 cars per year. It appears that 140,800 is a very favourable number of cars. The most unfavourable number of cars is 145500, when an extra barge has to be added.

17.6 Conclusions

The following conclusions can be drawn from this study:

- Technically it is possible to transport cars by a tug/barge system;
- Economically the tug/barge system is very profitable. For a volume of 140,800 cars the pay back period is 3 years. The maximum pay back period in less favourable situations is 5 years.

CHAPTER 18: CYLINDER TANK TYPE CHEMICAL TANKER

18.1 Introduction

Chemical tankers are complex and expensive ships, as they often carry hazardous cargoes. A lot of experience and know how has been gathered over the last decades and formalised in detailed design-rules and regulations from the International Maritime Organisation and the Classification Societies.
From a technical point of view, the present generation double-hull chemical tankers forms a milestone in design and safety. In spite of the increased technological sophistication of chemical tankers, one major problem seems difficult to solve over the years: the time spent in port (port time) of chemical tankers remains very long in relation to the time spent at sea. A major chemical tanker owner and operator, faces a port time of its entire fleet of deepsea tankers of around 40 percent. This causes a tremendous loss of charter revenues, and therefore this problem should be reduced in magnitude.
A study was undertaken in collaboration with the owner in order to understand in the greatest possible detail the reasons behind the large porttime. This study is described in the case-study book *"Innovation in chemicals shipping: port and slops management"*.
It led among others to the believe that on the basis of the current design of the chemical tanker, based on the integral rectangular tanks, often with stiffeners inside, corrugated bulkheads and heating coils, it is difficult to reduce the port time dramatically. Therefore it was tempted to redesign the chemical tanker. Central to this approach were the qualities inherent to the stainless steel cylinder type tanks. These tanks are easy to manufacture under factory conditions and through their ideal form, can withstand enormous pressures, and are easy to clean, as the heating coils are placed outside the tank and no internal stiffeners are used.

This case-study describes the design of a 44,300 m^3 chemical tanker based on the use of the cylinder type tanks. First, the design will be described and a first comparison will be made with the traditional design of more or less equivalent capacity. Thereafter the key-elements of the design will be highlighted.

18.2 Description of the design

18.2.1 Future design philosophy

The design of chemical tankers will be influenced by a number of developments that are partly triggered by initiatives outside of the sector itself. These are:

- *Elimination of polution from slops*
  Approximately 90 percent of the washwater of tanks (slops) can be legally pumped over board; it is to be expected that current regulations will become much more strict, as is already the case in certain fragile marine environments, such as the Mediterranean Sea, the Baltic Sea and the North Sea. The disposal of slops at shore reception facilities is very costly for the owner. One way to reduce costs is to reduce the slops production. In general, it is safe to assume that chemical tankers will become environmetally closed systems.

- *High quality standards*
  The quality standards of the chemical tanker industry will further increase and will ultimately resemble those of the food industry. The present tank types make it virtually impossible to achieve this.

- *3 Rs-design principles*
  Recently, design principles in shipping are going through a minor revolution, if one considers the change from rule-based to engineering first principles design. Yet another revolution in design principles is already on its way: durable technology. This can be typified by the the 3 Rs: Reduce, Re-use, Re-cycle. This will have profound consequences for the concept design of ships.

18.2.2 General arrangement and principal dimensions

The use of cylindrical stainless steel tanks in chemical tankers will be demonstrated on the basis of a large chemical tanker design, which is equivalent to a series of modern, existing chemical tankers, based on conventional design principles. This design is labeled Standard, and it is shown in **Figure 1**. The new design is shown in **Figure 2**. Its principal dimensions are given in **Table I**.

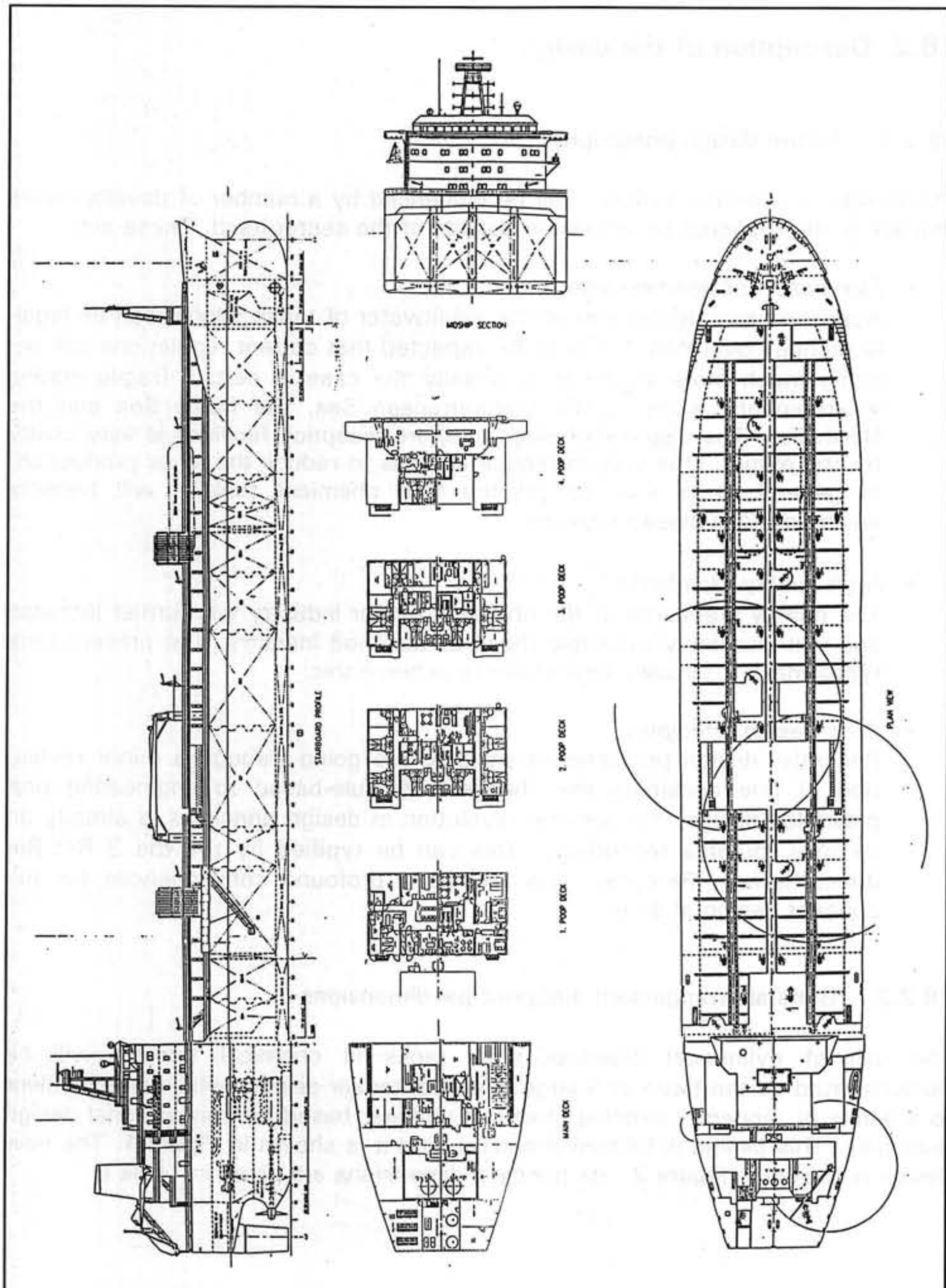


Figure 1: Standard chemical tanker

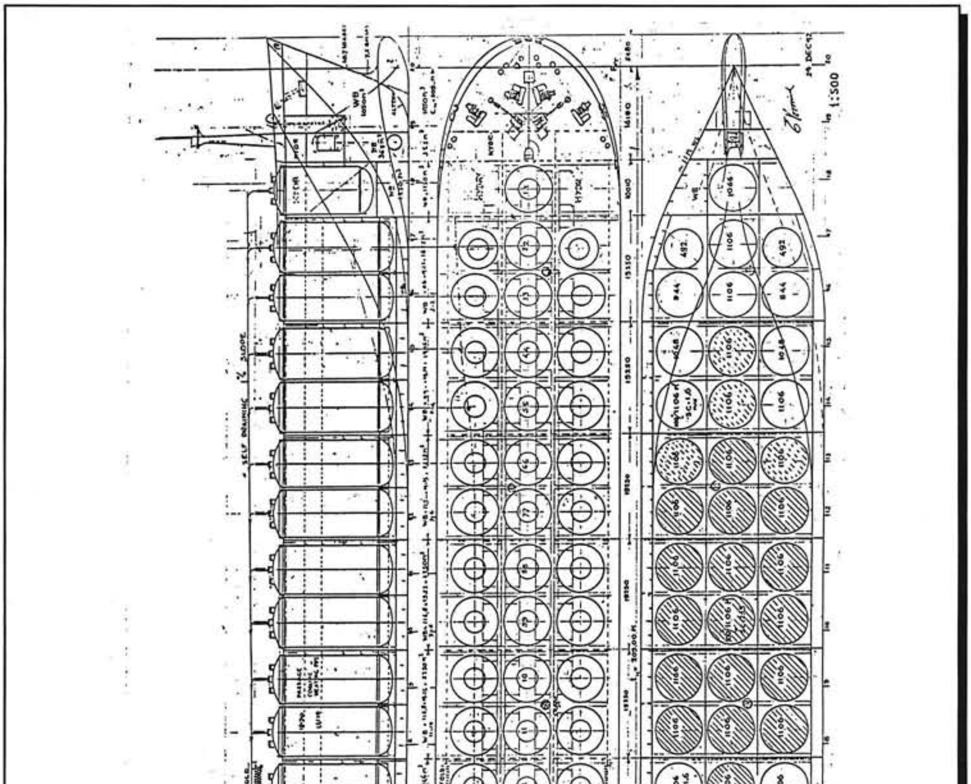


Figure 2: General arrangement cylinder tanker

Principal dimensions	Standard design	Cylinder tanker
Deadweight (tonnes)	35,400	(T=10.7) 35,497 (T=11.6) 38,292
Tank capacity (m^3)	38,021	44,300
Length over all (m)	182,3	218.5
Length between perpendiculars (m)	176,10	209.5
Breadth (m)	32,0	32.24
Depth (m)	14,0	21.5
Draught (m)	10,6	10.7
Light ship weight (tonnes)	12,600	18,043
Displacement (tonnes)	48,000	53,500
Block coefficient	0.78	0.722
Service speed (Knots)	13.5	17.75

Table I: Overview principle dimensions cylinder tanker

The cubic capacity of the 43 cylinder tanks and the 10 small slops tanks (optional) is 44,300 m^3. The cargo carrying capacity is determined by the specific weight of the cargo, the tank volume en the draught. The standard tanker has a design draught of 10.6 m. The displacement of the cylinder tanker at this draught is 53,497 tonne, which is composed as follows:

- Steel weight	11,982	tonne
- Engine room	1,572	tonne
- Outfit	1,488	tonne
- Stainless steel cylinder tanks	3,000	tonne
- Light ship weight	18,043	tonne
- Deadweight	35,497	tonne
- Displacement	53,540	tonne

The cylinder tanker has an extremely large volume and high freeboard. The draught can therefore easily be increased to 11.6 m. On this draught the deadweight cargo capacity is 38,292 tonne.

The service speed of the cylinder tanker is 17.5 knots, which is at least 2.5 knots faster than the Standard design. This is due to the low block coefficient (0.722 vs. 0.78) and the extra length of the ship. The fuel consumption is 62 tonnes/day, including the shaft generator for the auxiliary power.

18.2.3 The tanks

Figure 3 shows the cross section of the cylinder tanker. The width is 8.5 m. and the height 20 m. The capacity per tank is approximately 1,100 m^3. The capacity of all tanks is 44,332 m^3. Including 10 optional slops tanks (870 m^3), the capacity is 45,202 m^3. With a filling level of 98% the capacity is 44,300 m^3.
As the tanks are extremely protected, all tanks should be allowed by I.M.O. to carry type I cargoes. An advantage of the completely independent cylinder tanks, is that the problem of cargo incompatibility is fully eliminated.

All tanks are from stainless steel and are because of the ideal cylinder form easy to clean. According to calculations of a specialist of tank wash installations, the tank can be cleaned in less than 15 minutes (pre-wash), which represents a time saving of 75% compared to a conventional, integral tank of similar capacity. As a consequence the amount of wash-water diminishes proportionally. **Figure 4** shows the three dimensional drawing of the tank, the loadline and the tank cleaning installation.

18.3 Key-elements of the cylindertank chemical tanker

There are many advantages of the cylinder tanker compared to the standard design. In this paragraph, the key-elements will be highlighted.

<u>**Advantages**</u>

- All tanks are made of stainless steel and are independent. The absence of coated tanks improves the quality of the cylinder tanker;

- The ratio of tank surface to tank capacity of the standard tanker based on integrated tanks is 0.8 m^2/m^3 and of the independent cylinder tanker 0.6 m^2/m^3. This is a 25 percent reduction in tank surface for the same capacity. This reduces the amount of stainless steel and the wetted surface, which has to be cleaned as well;

- The steel hull and stainless steel tanks are built in parallel, which reduces the construction period with 3-4 months. This saves construction financing;

- The hull is relatively simple to build and resembles a double hull oil tanker or an open containership. The simple construction, and the absence of difficult stainless steel work at the yard, results in a reduced construction cost of the hull of the cylinder tanker;

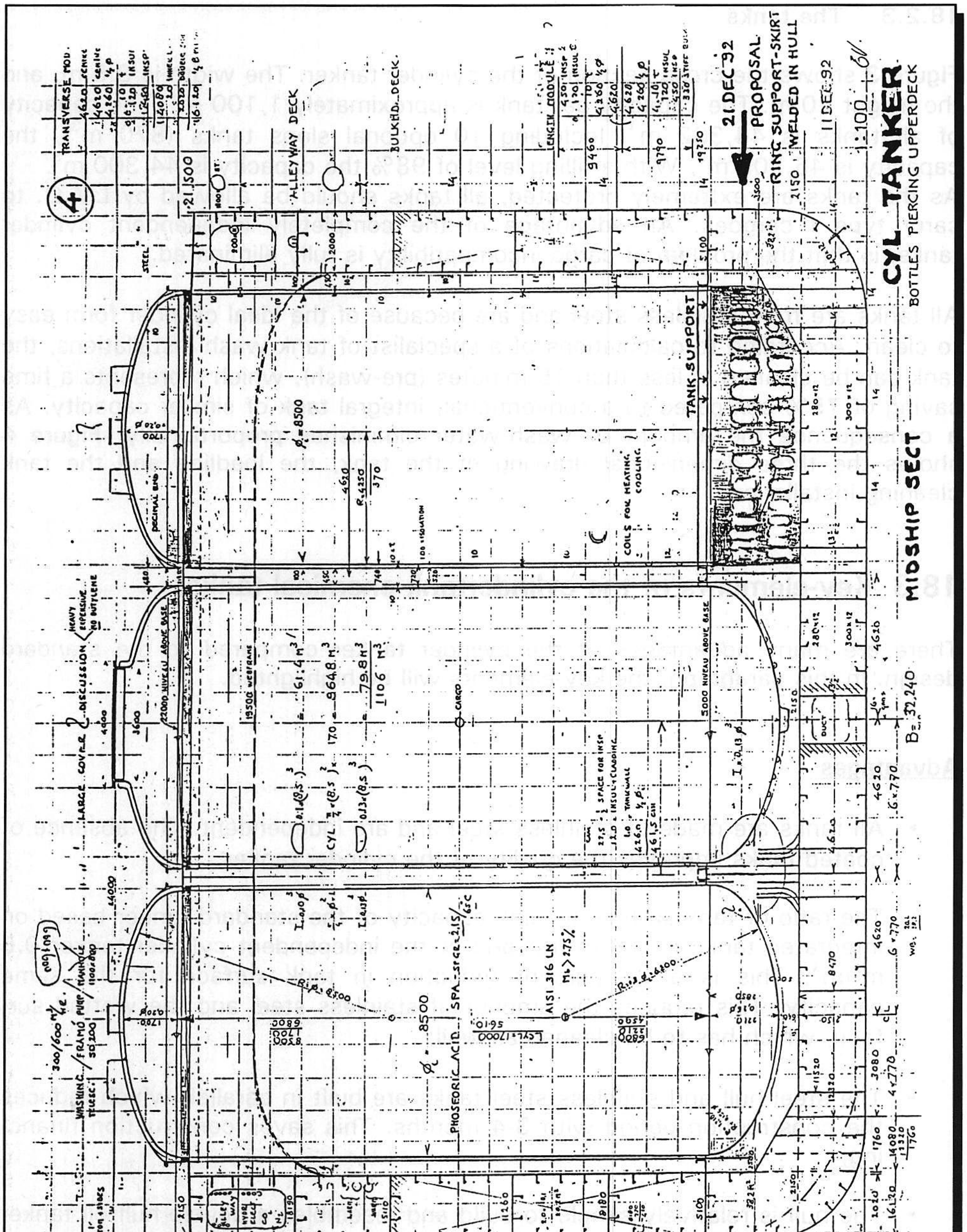


Figure 3: Cross section of the cylinder tanker

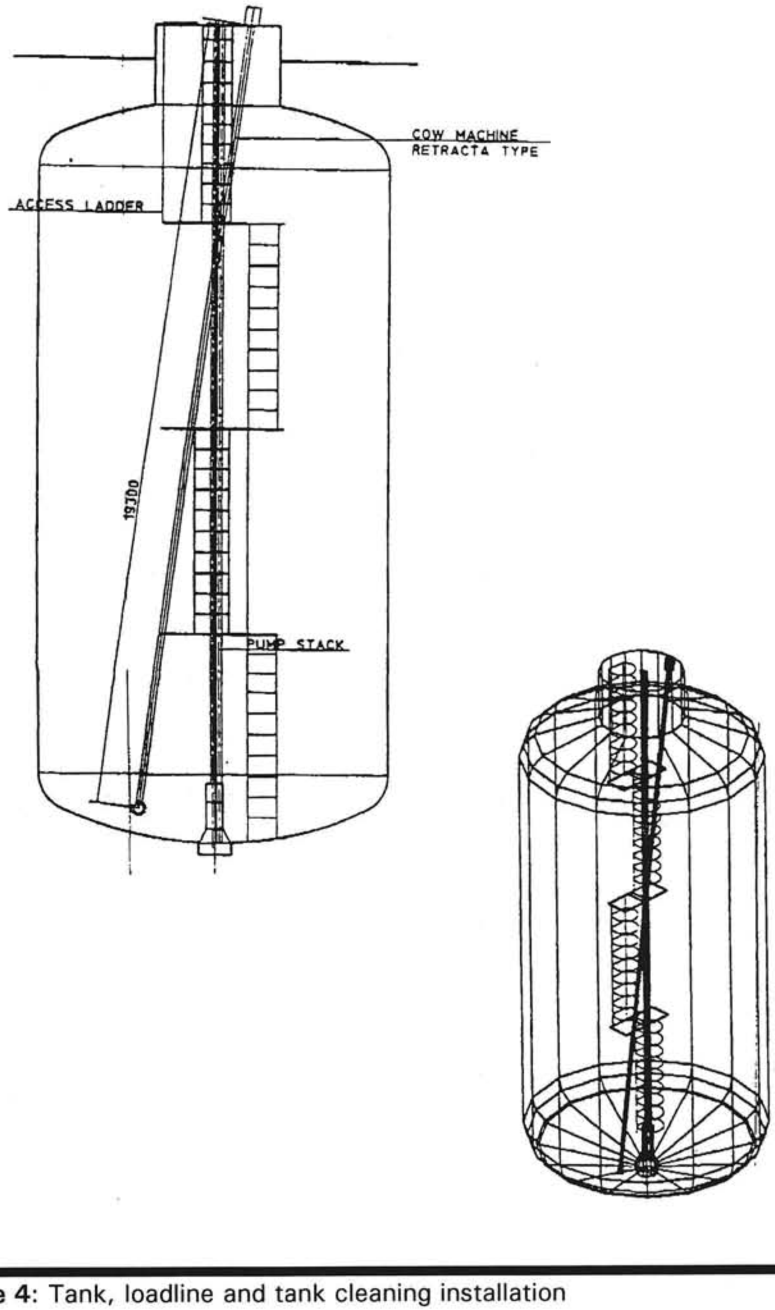


Figure 4: Tank, loadline and tank cleaning installation

- The stainless steel cylinder tanks are built under factory conditions to the highest quality standards, independent of the workmanship at the yard and the weather conditions;
- The construction of the cylinder tanker requires less sophistication from the yards, which increases the possibility to shop around and lower the prices. The tanks can be built on an other continent and transported with heavy lift vessels or on containerships to the yard;
- The depreciation of the cylinder tanker is substantially lower, as the stainless steel tanks can be taken out of the hull at the end of the commercial life of the tanker and even reused in a new tanker; this has a positive effect on the 3 Rs design philosophy; the residual value of the stainless steel weight, which is normally lost when scrapping standard chemical-tankers, will increase with the value of the stainless steel weight of the tanks; consequently, the annual depreciation can be reduced;
- The cylinder tanks are independent and insulated, while the heating/cooling coils are placed on the outside. Therefore traditional compatibility problems (product and heat) and contamination problems from cracking will be eliminated;
- The cylinder tanker has in fact a triple barrier (double hull and tankshell) and should therefore be allowed to transport IMO type I products in all its tanks;
- The cylinder tanks can be designed to transport super-phosphoric acid (specific weight 2.15). They can therefore also become pressure vessels, and transport certain chemical gases, in combination with cooling of the tanks; this may open up niche-markets;
- Some tanks in the ship can be designed to transport high-heat products while others may transport refrigerated cargoes at little extra cost;
- The insulation around every cargo tank, reduces the energy use for heating and cooling purposes once the cargo has reached its temperature;
- The cylinder tanks have practically all the same capacity. This, in combination with the absence of compatibility problems, makes commercial and operational planning of cargoes easy and fast. Revenues may thus be improved during the booking of last minute spot cargoes;
- The cylinder tanks can be filled at any rate, as the relatively small diameter of the tanks limits the free water surface effect, creating again more flexibility;

- The cylinder tanks are easy to clean because of their ideal form, small diameter (large impact of waterjet), and through the absence of coils within the tanks (no shadows); it is estimated that a reduction of 75 percent of the water use can be achieved and an equivalent reduction in washing time;

- The lower slops production saves time in port for washing and reduces the cost of delivery of slops to shore reception facilities, and is in anticipaction of stricter disposal rules;

- The cylinder tanks are ideally supported and do not form part of the hull's structure, so the ship's motions will not create cracks in the tanks; this will reduce future cargo and P&I claims;

- The cylinder tanker has a very favourable damage stability behaviour, because of the absence of longitudinal bulkheads, which improves the saftey in case of a collision;

- The H&M and P&I premiums will be lower for a cylinder tanker because of the damage stability, triple barrier and elimination of cracking in tanks aspects;

- The cylinder form of the vertically placed tank makes it worthwile to install automated washing machines in the tanks (multistage fixed installed, or retractable). This may reduce the number of ratings on board;

- The cylinder tanker will be longer than the standard chemical tanker. This may increase the optimum service speed. The corresponding increase in fuel consumption may be offset by the shorter sea time of a journey and increased productivity of the tanker. Applying the same speed, the longer tanker will have a 10 percent reduced fuel consumption. The higher economic service speed, may lead to an annual extra earning potential of more than 30 days charter hire;

- The cylinder tanker has a high freeboard, which allows the ship to sail at an increased draught. This increases the commercial deadweight capacity and the earning potential of the ship with approximately 10 percent (the cylinder tanks have the extra volume to accomodate this extra deadweight);

- The absolute smoothness of the cylinder tank's inner surface and the excellent cleaning characteristics, will set a new standard of quality in the chemicals shipping industry. This should command a premium in the freight rate, or alternatively, should lead to an advantage over a standard vessel in a bad market.

Disadvantages

The long list of advantages is partly counterbalanced by some disadvantages of the design. These are briefly discussed below.

- The independent tanks do not form part of the double hull structure. Consequently, the light ship weight of the cylinder tanker will increase in comparison with the standard tanker. The extra steel weight increases the building cost, it is estimated that this increase is in the order of magnitude of 5 percent. It should be borne in mind that the tanks in the Standard design are not all stainless steel, but are partly coated, in particular the wingtanks. Therefore the quality of the designs is not realy comparable;

- The utilisation of the ship's hull is quite poor by the cylinder tanker. There is a lot of empty space around the cylinder tanks. This increases the gross tonnage of the ship, which will have consequences for the port and canal dues. The increase in costs depends on the number of ports and the routes (Panama or Suez Canal, etc.). These costs per year are approximately 40 percent higher than those of a standard chemicaltanker;

- The cylinder tanker is a completely new design, although it may be compared with gastankers. Shipyards may be initially hesitant to contract such a ship as this innovation may pose some extra costs and risks for the yard. This is, however, a problem, that every innovation in shipping faces. History is on our side to prove that this drawback will eventually be overcome.

18.4 Financial evaluation

To evaluate the performance of the cylinder tanker, it is compared to the standar design. In this section an overview is given the differences in values and prices are estimated. **Table I** gives the principal dimensions of both ships.

18.4.1 Construction costs

The construction cost of the cylinder tanker is estimated by the following formula:

$$Construction\ Cost = W_{LSW} * C_{sp} * C_F$$

Where:

W_{LSW} = Light Ship Weight;

C_{sp} = Specific building cost per kilogram (US$/kg); this is estimated from the course of the specific building costs in the period 1965-1992;

C_F = Complexity factor; this is a multiplication factor that expresses the complexity, and with this the labour costs, of the ship type. For example, the factor for a VLCC is 0.75, for a chemical parcel tanker it is at least 1.6.

Standard tanker:

- Light ship weight 12,600 tonne
- Cost/kg. US$ 3.90
- Complexity factor = 1.6

Total costs	***US$ 80 mln.***

Cylinder tanker:

- Light ship weight (excluding stainless steel tanks) 15,043 tonne
- Cost/kg. US$ 3.00[3]
- Complexity factor 1.0

Costs light ship	US$ 45 mln.

- Stainless steel tanks 3,000 tonne
- Cost/kg. US$9.00

Costs stainless steel tanks	US$ 27 mln.
Costs pumps, piping, instal. etc.	US$ 13 mln.
Total Costs	***US$ 85 mln.***

18.4.2 Depreciation

The construction costs of the cylinder tanker are almost in line with those of the standard tanker. The simple hull form (bulk carrier) of the cylinder tanker, makes it possible to have the ship constructed at unsophisticated yards and the cost/kg can therefore be low.

Another advantage of the design is that the expensive stainless steel tanks (US$ 27 mln.) can be built in parallel with the hull, thus shortening the construction period. This also creates an added value at the end of the commercial life of the ship. As the cylinder tanks are independent, and do not deteriorate while in use, they can simply be taken out and be reused in a new ship.

The depreciation of the two designs is shown in **Figure 5**. The annual depreciation of the cylinder tanker is US$ 0.75 mln lower than that of the standard tanker (US$ 70 mln./20yrs. = US$ 3.5 mln./year versus US$ 55 mln./20yrs. = US$ 2.75 mln./year)

[3]Because the hull of the cylinder tanker does not require stainless steel for the tanks, the cost per kg. of the ship is lower than for the standard design

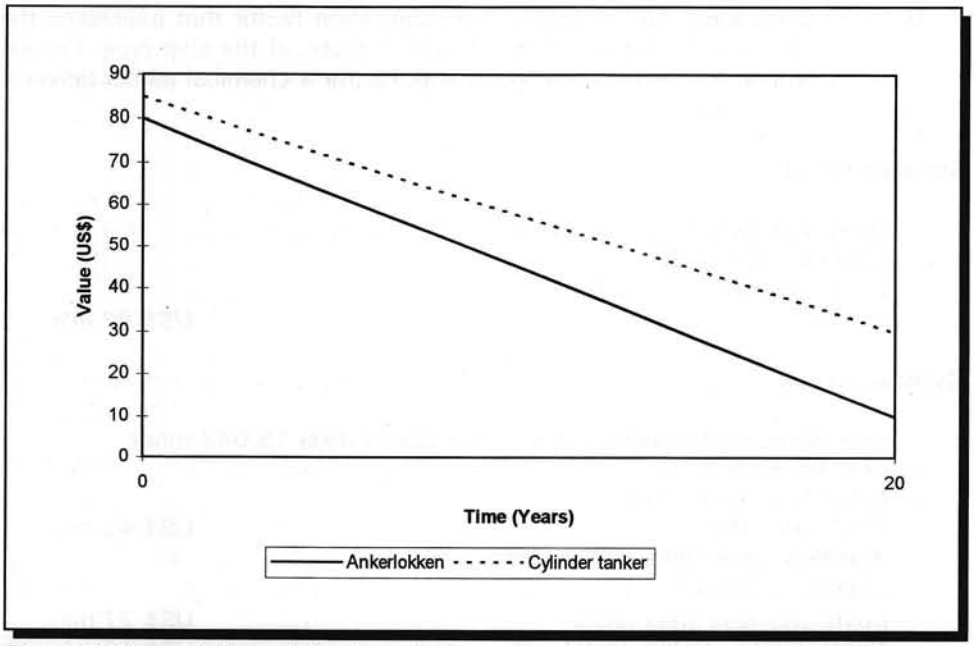


Figure 5: Depreciation of the two designs

18.4.3 Financing

For comparison's sake only the cost difference of US$ 5 mln. is considered. A part of this sum is covered if one takes the financing cost during the construction into account. Because of the parallel construction of the hull and the tanks, the construction can be reduced by at least four months. On basis of an average investment during construction of 50% of the new building price and an interest rate of 8%, the interest savings of the cylinder tanker are:

$$0.5 * US\$\ 85mln. * \frac{4}{12} * 8\% = US\$\ 1.13mln.$$

This lowers the cost difference to US$ 4mln. The interest payments over a ten year period, when discounted are:

$$US\$\ 4mln. * 8\% * 6.7\ (present\ worth\ factor) = US\$\ 2.14mln.$$

18.4.4 Operating cost

The operating or running costs of the two designs will differ in some important areas

Crew
Because the cylinder tanker has a remotely controlled pumping and tank cleaning system, the number of crew members could be reduced by 5. The savings per year are estimated as follows:

$$5 * US\$\ 2{,}000 * 12\ months\ = US\$\ 120{,}000/year$$

Repair and maintenance
No mayor difference between the standard tanker and the cylinder tanker.

Stores and provision, lubrication oil
Only the lubrication oil consumption will be slightly higher because of the large capacity of the main engine.

H&M, P&I insurance
The value of both ships is almost equal, so premiums should not differ too much.

Ship management costs
The overhead costs of managing the ship are in principle identical for both ships.

18.4.5 Voyage costs

The variable costs consist mainly of fuel consumption, port and canal dues, and slops disposal.

Fuel cost
Because of a lack of information on the speed/fuel consumption relationship of the standard tanker a fuel consumption of 45 tonne/day, 40 tonne for propulsion and 5 tonne for auxiliaries, is assumed, for a service speed of 15 knots. The annual bunkers, on the basis of 40% port time for loading/discharging and a fuel price of US$ 82 per tonne is US$ 867,970.

The cylinder tanker has a service speed of 17.5 knots and a shaft generator of 1125 kW. The total fuel consumption is 62 tonne/day. If the ship sails at 15 knots, the fuel consumption is almost equal to that of the standard tanker.

Port and canal dues
These costs are based on the tonnage measurement, which can be GT, NT, or Panama Canal or Suez Canal adjusted measurements, or adjusted for segregated

ballast tanks, etc. The standard tanker is 22,000 GT, which compares favourably with the 39,500 GT of the cylinder tanker (+ 80%).

As port and canal dues do not proportionally increase with an increase in GT, the cylinder tanker should be approximately 40% more expensive. If the ship makes only roundtrips between Rotterdam and the U.S. Gulf, then, based on 40% port time, the annual cost difference could be:

▸ Standard tanker	:	9 trips * US$ 50,000	= 450,000
▸ Cylinder tanker	:	9 trips * US$ 70,000	= 630,000
			US$ 180,000

Slops disposal cost
Slops disposal costs much money, which is often paid by the shipowner, and sometimes by the shipper/receiver, depending on the conditions in the contract.
The slops production depends on many factors, such as tank configuration, washing-machine installations, the type of cargo, etc. The cost of disposal depends on the type of cargo, the amount of slops, the port, etc. Because of the complexity of this issue, it is sufficed with the statement that the cylinder tank can be cleaned by the retractable machine with 75% less water consumption, In theory, the slops costs are proportionally lower.

18.4.6 Commercial aspects

The cylinder tanker has many commercial advantages, of which only three can be objectively quantified. These are:

- More voyages in the same period, because of higher service speed of the cylinder tanker;
- Less port time, and therefore more voyages because of the short period required for washing the cylinder tanks;
- 8% extra deadweight capacity.

Higher service speed benefits
The difference between the average service speed of the standard tanker and the cylinder tanker is 2.5 knots. This means that while sailing 219 days per year, the higher speed will create an extra 2.5/15 * 219 = 36.5 days which can be used for a voyage. This represents a potential extra charter revenue of 36.5 days * US$ 25,000/day = US$ 912,500 per year.
The greater service speed will cost extra fuel, ± 62 - 45 = 17 tonne/day, or 17 tonne/day * US$ 82 * 36.5 days = US$ 50.881. *The net benefit of the 17.5 Knots speed is thus US$ $861.619.*

Shorter port time
The traditional chemical tanker spends 40% of the year in port for loading, discharging and tank washing. With 18-20 port calls per year, this leads to an

average of 7-8 days per call. Fast and efficient cleaning of the cylinder tanks will reduce this time with at least 1 day per call, so 18 days a year. The extra earning capacity is 18 days * US$ 25,000/day = US$ 450,000.

Extra deadweight capacity
The cylinder tanker is able to increase its deadweight capacity by almost 3,000 tonne, as the high freeboard allows a draught of 11.6 m. For 10 roundtrips per year, the potential extra earning capacity is 30,000 tons. With a freight rate of US$ 40/tonne, this is US$ 1,200,000 per year. Only 25% or US$ 300,000 is taken into account.

Table II gives an summary of the costs and benefits, shown in this section.

	Type of costs	Amount difference (US$*1000)
Benefits	Lower slops cost	not calculated
	Lower crew cost	0.12 /year
	Higher deadweight	0.30 /year
	Shorter port time	0.45 /year
	Higher speed	0.68 /year
	Lower depreciation	0.75 /year
Costs	Higher net investment	2.10
	Higher port dues	0.18 /year

Table II: Cost overview

Stolt-Nielsen design

The advantages of the cylinder tanker have been realised by Stolt in yet another way. Their advanced design is based on the classic parcel tanker (**Figure 6**). The innovative aspect of this all stainless steel design, built by Danyard, is the two longitudinal cofferdams, which achieve a good improvement of the cargo incompatibility problem, but not as good as the cylinder tanker. The stainless steel tanks can also be removed at the end of the commercial life of the tanker, although some mild steel has been used in the tank construction.

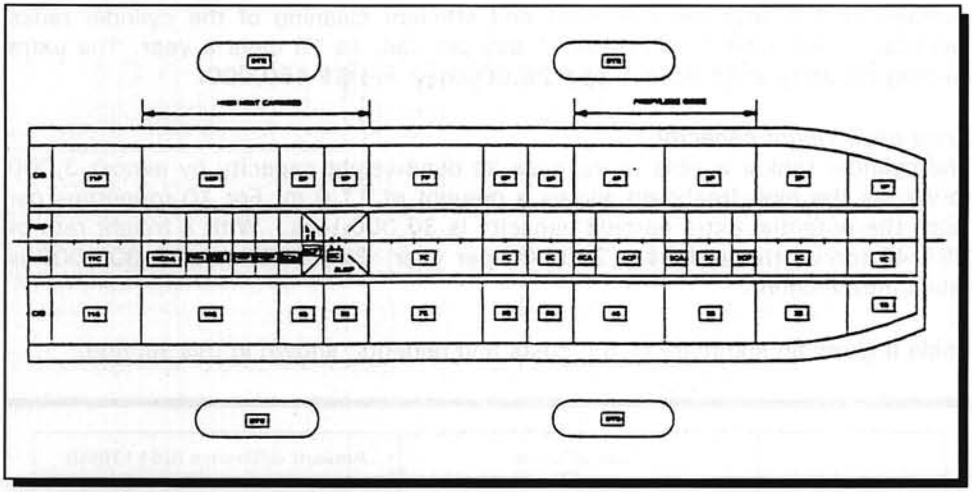


Figure 6: Stolt Nielsen tanker

CHAPTER 19: DESIGN OF AN INTEGRATED OIL SUPPLY SYSTEM

The systems approach to design in shipping can be illustrated by a relatively old example, published in R.G. Coyle's *"Management System Dynamics"*, but which is still relevant to demonstrate the holistic approach required in the early stages of a design process. System modelling is an excellent way to define the problem (or opportunity) in relation to its relevant environment. It implies the definition of boundaries and parameters, as well as their interaction over time.
The case-study focusses on the *Design of an Integrated Oil Supply System*; it is advisable to read the full description of the case-study in Coyle's book, instead of the abbreviated version that follows hereafter.

19.1 The design problem

Introduction

The major oil companies operate in various parts of the world and have to ship their crude oil to North Western Europe (NWE) for further processing and for eventual sale as finished product. It is with this aspect of their operations, the so-called *supply system*, that this case is concerned. The data used in the model are based on what they used to be in 1970 in a real company, and the policies in the model are versions of what a large oil company might have done in the days of relatively low oil prices, and practically complete freedom from control by the producing countries.
One of the problems which might be used as a testing-ground for evaluating system dynamics could be stated as follows: "*We (the oil company) already have a very effective process for managing the shipping, storage and refining of crude oil and oil products (collectively called the supply system) which we have carefully evolved over many years. Is it, however, possible to use system dynamics to evaluate alternative ways of controlling such a system in a 'typical' company?*"

Sources of shipping

For simplicity, the geographically separate oil-producing areas can be grouped into long-haul and short-haul sources. The voyage times for these two categories are 67 days and 25 days respectively and the proportion of short-haul oil to total imports will be called the short-haul ratio. Clearly the difference between the respective voyage times means that a small change in the short-haul ratio would have a large effect on the number of ships required to transport a given total flow of oil.

A typical oil company owns and operates a number of oil tankers which, however, provide only part of the required shipping. The balance is made up of vessels chartered from independent owners. There are two types of charters: spot charters (S/C) and time charters (T/C).

Spot charters

The tanker is taken for one voyage only and, after completing it, may be chartered by some other company. Owners keep their tankers available in the vicinity of the oil loading ports so that prompt availability (within 24 hours) and loading can take place.
Chartering takes place through a highly developed tanker market, driven by shipbrokers, who match demand and supply. The charter rate paid for a vessel is expressed in World Scale units, with WS100 representing, we assume £4 per tonne of crude oil transported from Bahrein to Rotterdam. This is based on a ship of stated size steaming at a stipulated speed (a 'notional' tanker) and for any actual ship or any other voyage the actual cash payment is readily calculated. The tanker market is very volatile and prices may range from WS30 to WS300 or more. If charter rates become very low, tankers may be laid up and become unavailable on short notice.

Time charters

The tanker is chartered for an agreed period of time, ranging from 6 months to 3-5 years, and is at the complete disposal of the charterer during this period. The rate paid for T/C tankers is fixed by the charter market and is expressed in £/year for the tanker, which can be converted into WS Equivalents.
Time chartering can be done in two ways. In immediate time chartering the vessel presents for service within about a month. In distant time chartering the charter contract is signed now, but the vessel presents at an agreed date in the future, possibly several months ahead, which is called the presentation band. Distant chartering is used to ensure security of supply of good tonnage during the high-demand season (winter).

Dynamics of the design problem

The key to the dynamics is that, in aggregate, the demand for refined product shows a marked seasonality with the peak at mid-winter. Individual products have different patterns, which can to some extent be dealt with by short-term planning procedures. There remains the residual seasonality in total product offtake which means that crude movements must also be seasonal, though the amplitude may not be the same as that of product offtake.
The simplest way of providing for a seasonal demand is to have just enough owned and time chartered shipping to meet at the mid-summer trough, with a small margin against overchartering, and to spot charter enough shipping, as when needed, to fill the winter peak. This is shown in **Figure 1**.

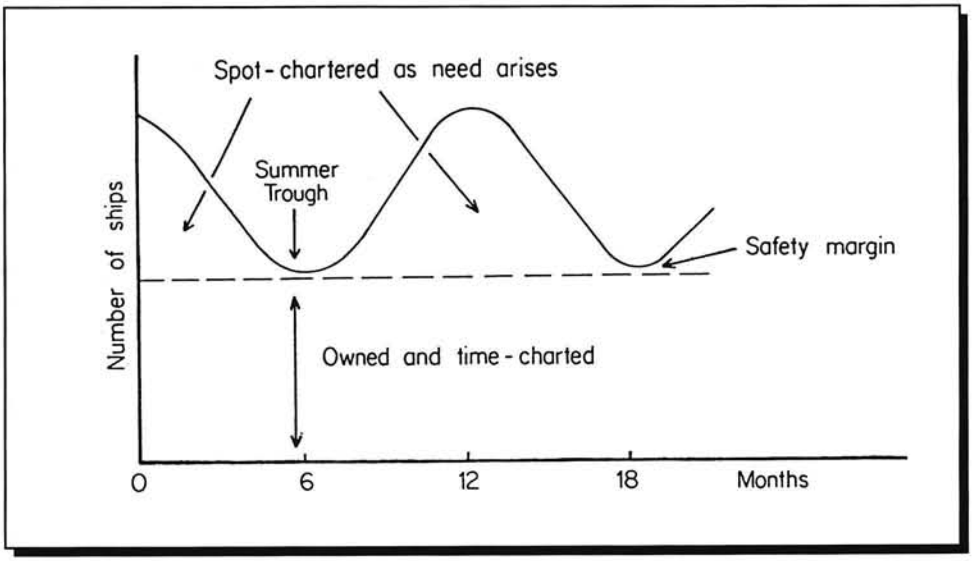


Figure 1: A simple view of the shipping problem

If the seasonal amplitude is reasonably constant, an alternative approach shown in **Figure 2** can be considered. This figure represents a forecast, at one point in time, of the next 18 months, and not 18 months as they pass. If no further time chartering is done, then, other things being equal, the existing T/C fleet would decay as ships come to the end of their charters. Ideally, extra time charters would be placed so that the owned T/C total would miss the troughs in shipping demand by a small amount, called the spot-charter fraction (SCF), in order to avoid over chartering if at all possible. The area between the dashed line and the shipping requirement curve then has to be spot chartered whatever the price, or stocks have to be run down. In the model the SCF is taken as a simple constant of 5%.

Many of the complexities of the situation cannot be shown in **Figure 2.** Basically, the anticipated shipping requirement is rather elastic and is affected by several factors. In discussing these factors, it should be borne in mind that the model refers to the pre-1973 oil crisis situation. Since then, the general changes in the world environment have markedly affected the way things might have to be done. The complexities are caused by three factors: forecasting of demand, production and oil stock policies, and price expectations of charter rates.

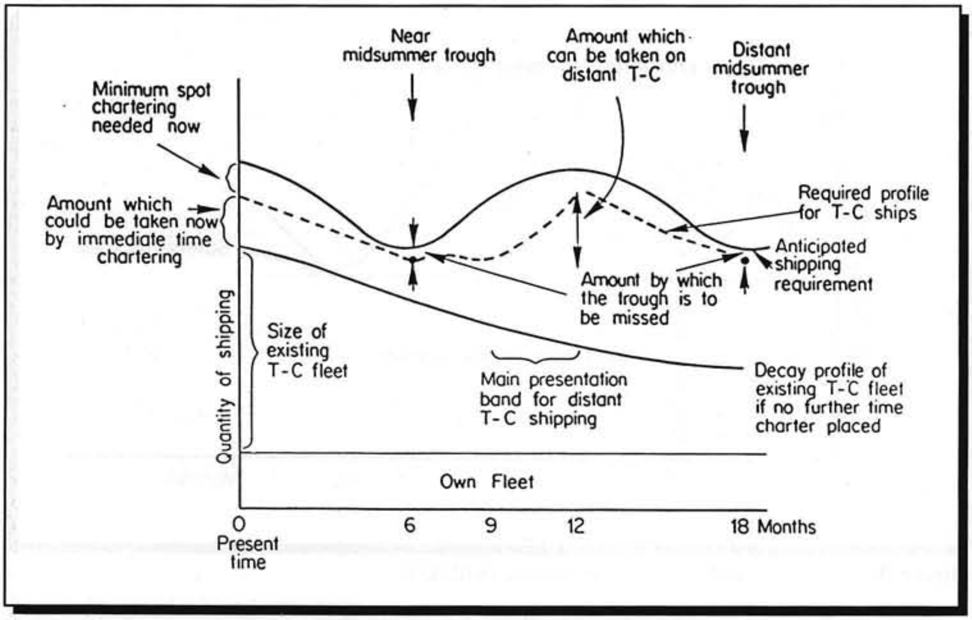


Figure 2: An alternative approach to the shipping problems

Measures of system performance

The simplest measure for the performance of a supply system is the cumulative expenditure on all shipping over a long period (10 years). The length is dictated by the 3-5 year time charter duration and the need to allow for dynamic behaviour to work its way through the system.
Furthermore, the stability of the rate of spending on shipping, the oil in stock, the refinery utilisation, and so one are all performance indicators.

19.2 System modelling

Initial design of the oil supply system

Figure 3 shows the causal diagrams of the system, which is basically driven by the demand for oil in NWE which derives from the growth of GNP in the region. This variable is an exogenous factor and the variations and its implications may be tested on the model behaviour.

On the left-hand side of the diagram, the drive is transmitted through the refinery sector, so if the sector's gain can be attenuated, it should be possible to insulate the model structure from seasonalities, and vice-versa.

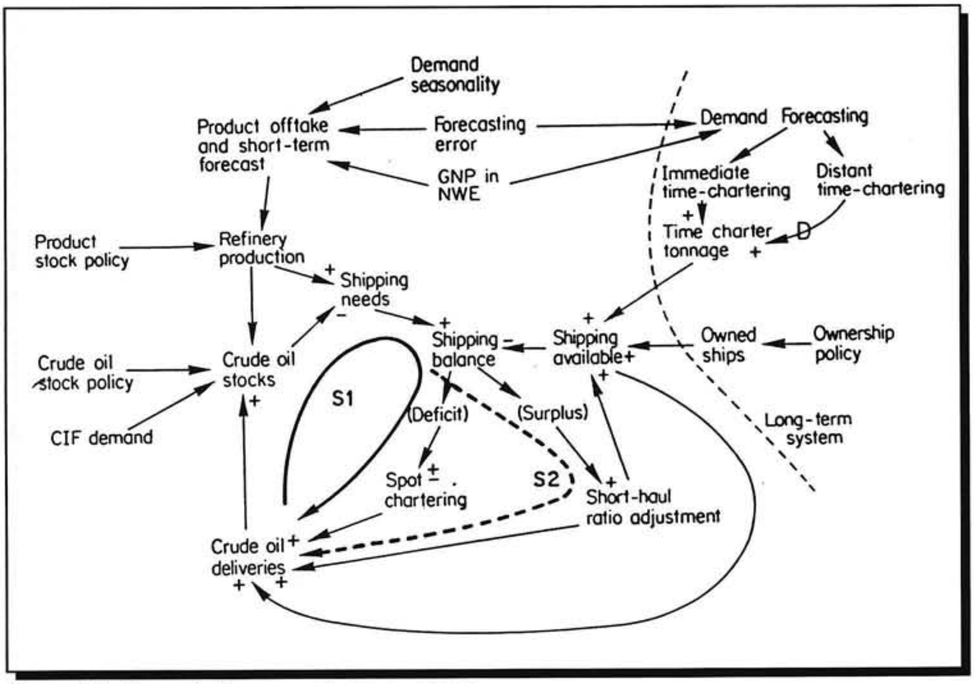


Figure 3: Causal diagram of the system

The central area of the diagram shows the main control mechanisms on shipping. Essentially there are two loops, S1 and S2, both negative. These together constitute a short-term control in the sense that they provide a response to external shocks which comes into play very quickly but which does not last very long, as spot chartered tankers are only effective for half of their voyage time.
The long-term is dealt with by the control on the right-hand side of the diagram. The salient feature is that the long-term system simply drives the short-term one, but there is no feedback from the main control loops to the long-term input. Thus all the current stocks to the model arrive via refinery production and crude oil stocks, and are met exclusively by S1 and S2.

Charter rates in the model

Charter rates of tankers are notoriously unstable, as shown for the five year period of 1969-1972 in **Figure 4**. The model uses again, like with GNP, exogenous values as inputs for the development of charter rates over the ten year simulation period. The alternative would be to develop an endogenous charter rate module within the current supply system model. This would become so complicated, in fact a world economic model, that the focus on the real issue, the oil supply system of an oil company, would be drowned in the environmental complexity.

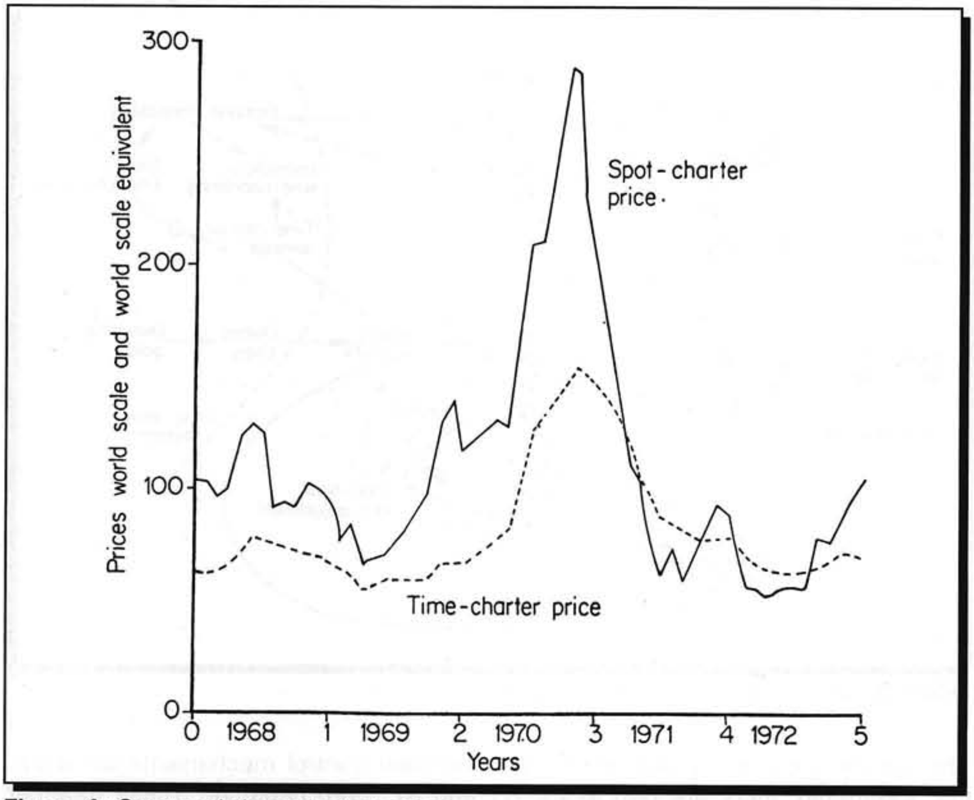


Figure 4: Spot and time charter prices

The results of these assumptions show that the basic design of the system is good, in the sense that the performance indicator 'total amount spent on shipping' is remarkably insensitive to forecast errors.

In searching for improvements it would be easy to embark on a vast programme of computer simulations with little guidance as to what should be simulated next; it is therefore useful to examine the feedback structure of the first design in more detail, as shown in **Figure 5, Figure 6** and **Figure 7**.

There are two main areas in which improvements to the control structure can be seen to be possible: the crude oil control and the shipping control mechanisms.

The structural changes in the model and their quantitative implications can be summarised in two scenarios, based on the least cost system, and the smoothest system. One of the results (least cost) is shown in **Figure 8**.

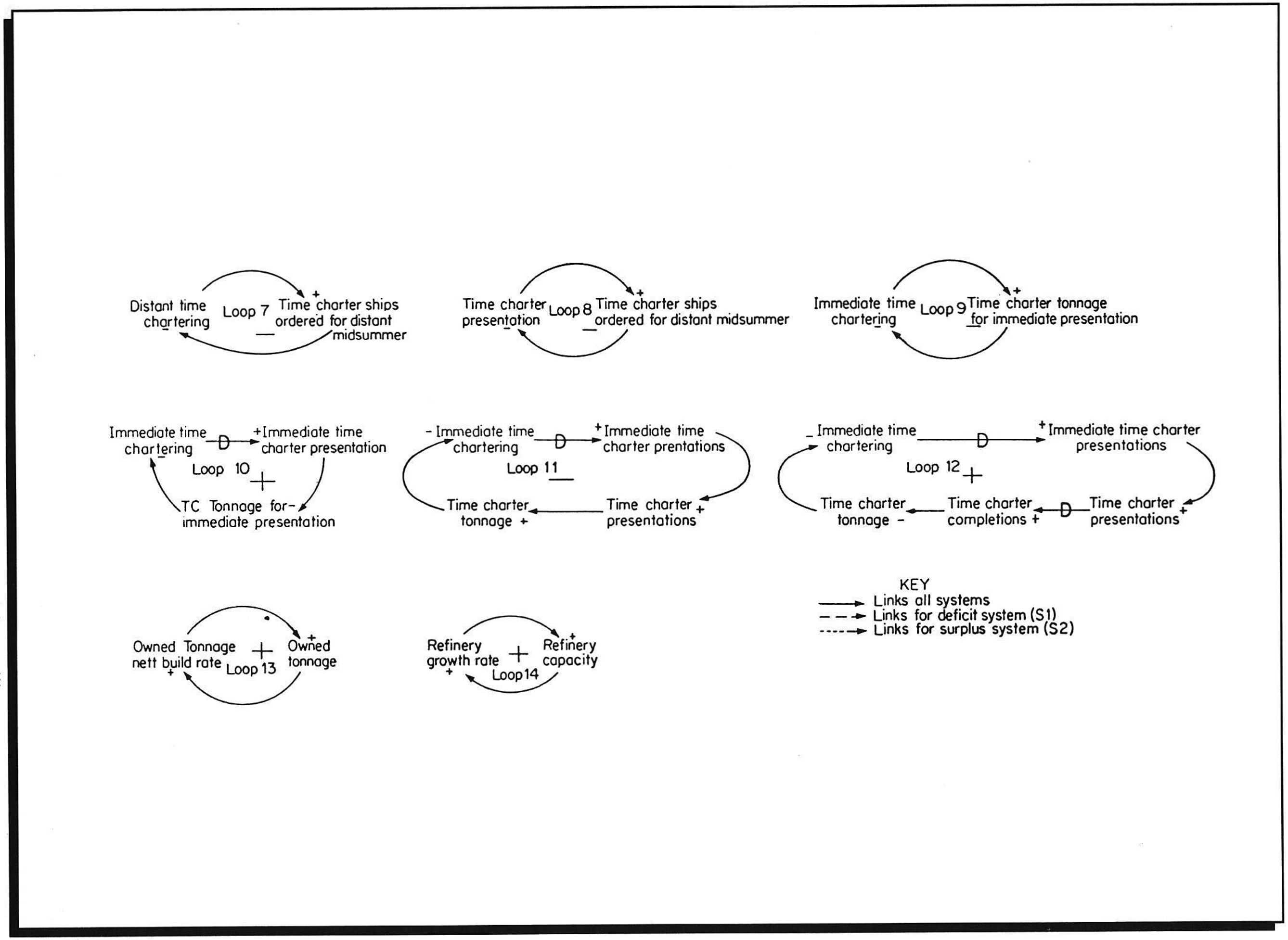


Figure 5: Principal feedback and loops and system drives (I)

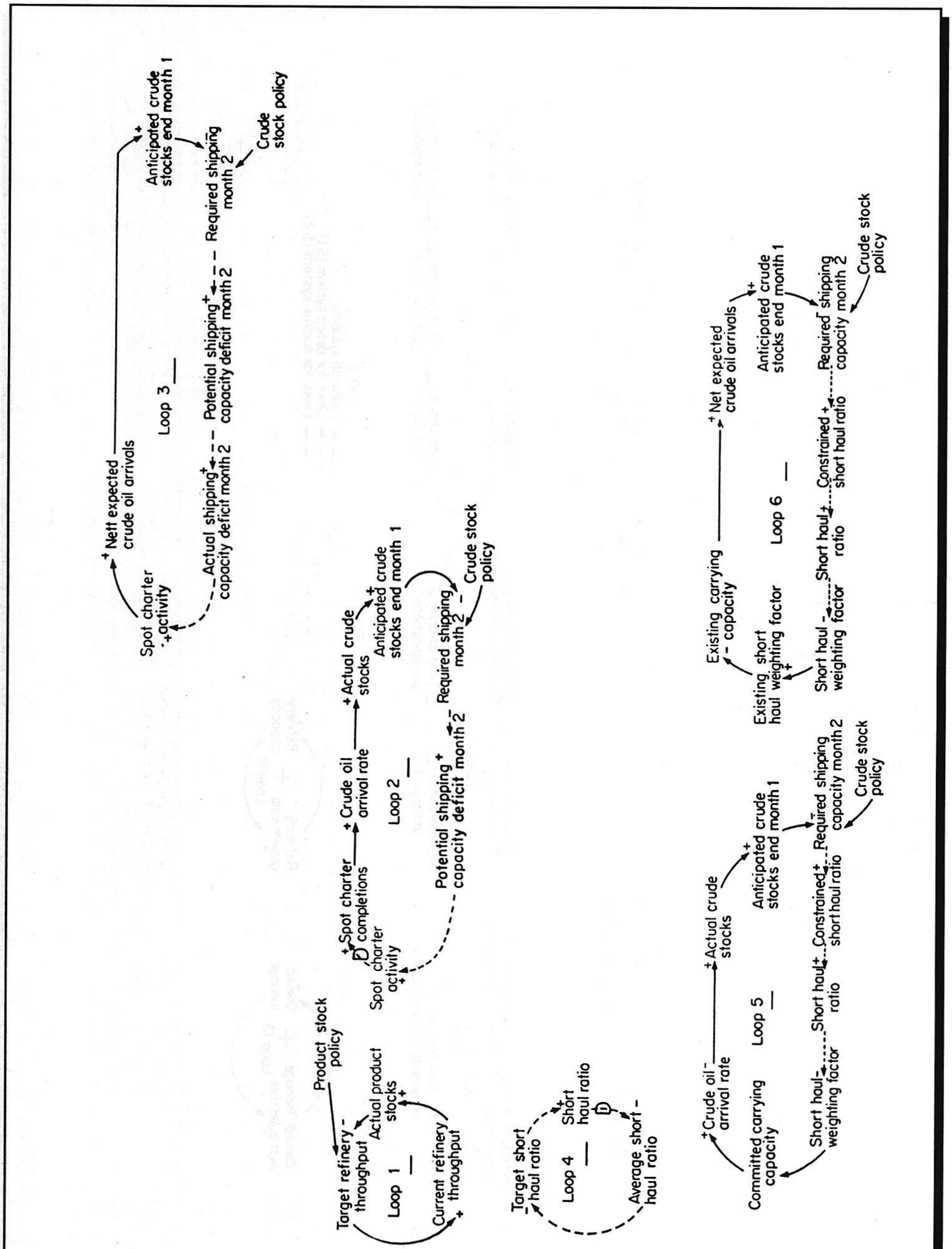


Figure 6: Principal feedback and loops and system drives (II)

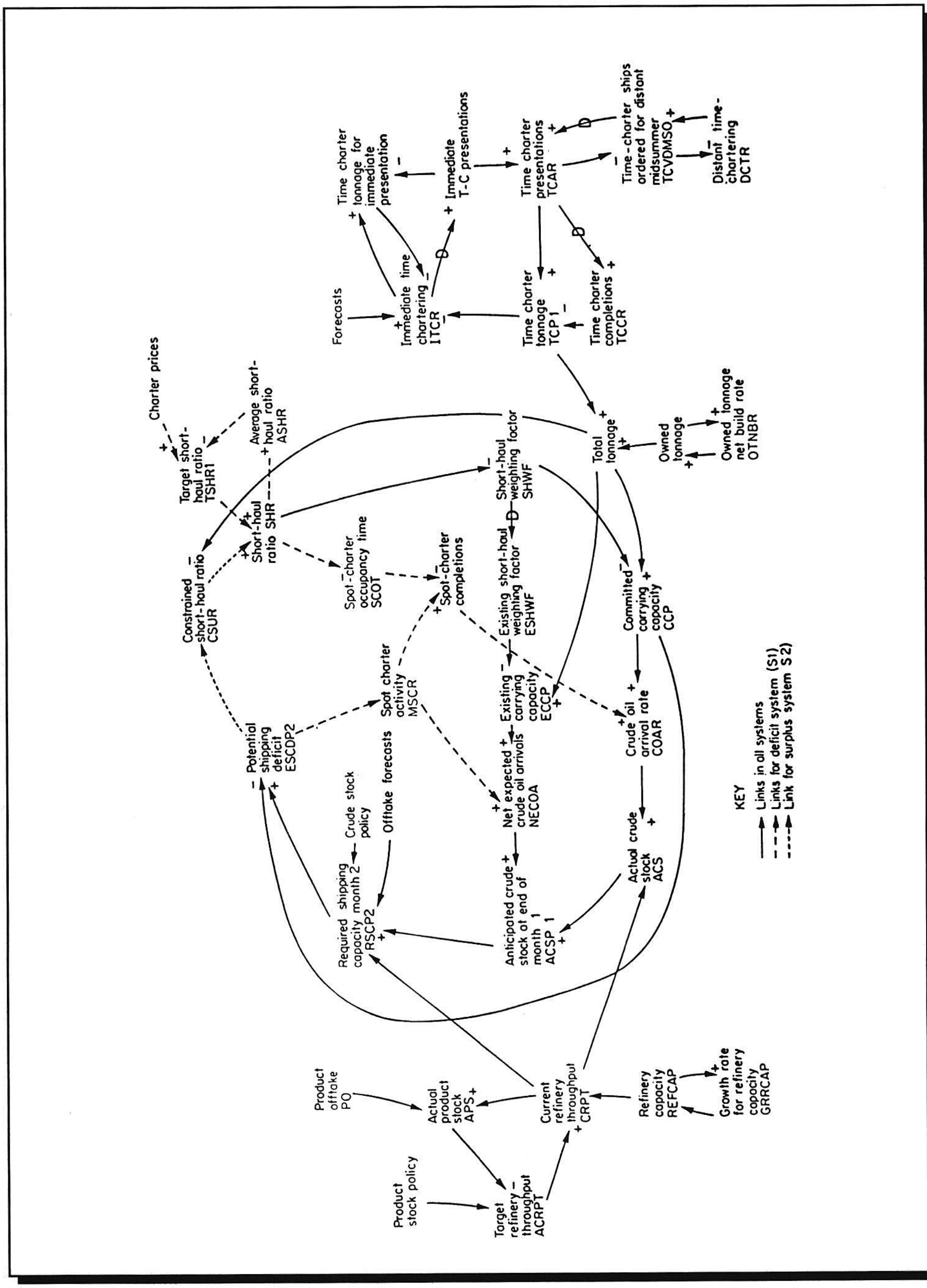


Figure 7: Principal feedback and loops and system drives (III)

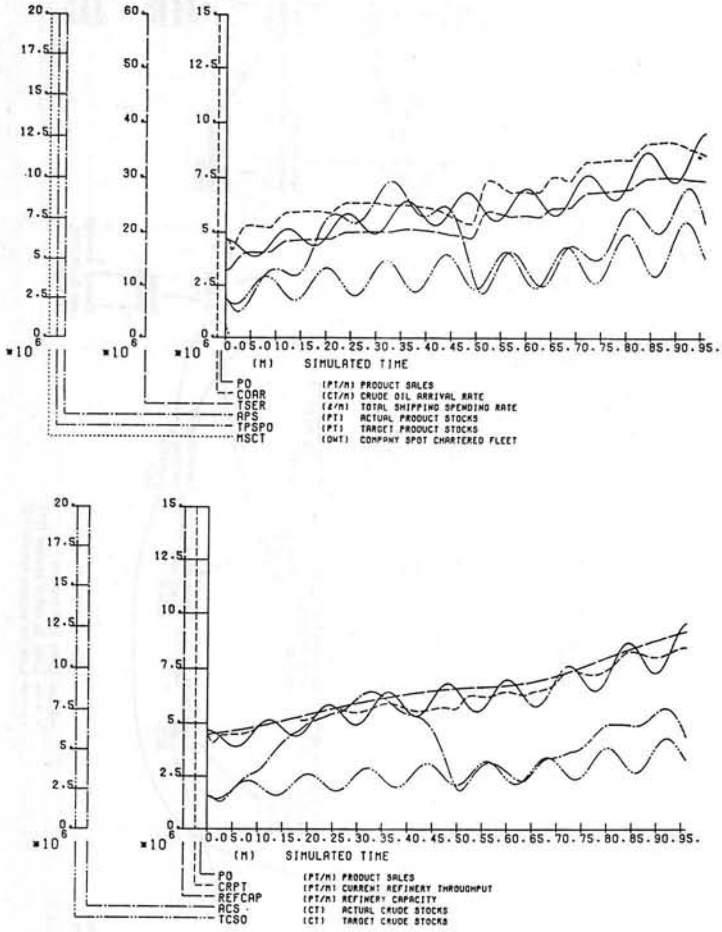


Figure 8: The cheapest system

Shipping questions

The model of the supply system can also be used to define the optimal tanker size for the company, or the optimal combination of tonnage and service speed; the increase from a supertanker to a vlcc or from 12 knots to 14 knots, will have profound implications. The model shows the complexities of the relationships, and also that a ship (tanker) is part of a logistical system, in which it provides just a link (although essential). Defining the best tanker for a company, may only be valid for a certain period, as the dynamics in oil shipping are such that the 'optimal' tanker is a moving target.
That is the reason why the oil trade has developed standard tanker sizes, based on a standard volume (1 million barrels, etc) or draught (Suezmax, Aframax, VLCC). The construction of a dynamic model of the logistical system, is an essential part of the design process.

CHAPTER 20: INNOVATION IN FOREST PRODUCTS SHIPPING

20.1 Introduction

The term *forest products* covers a wide range of different products, which all have in common that they are based on the same material: Trees. Logs can be transformed into the following intermediary of end products: Wood, wood pulp, paper and board. Wood, wood pulp and board can be transported very effectively, in an uncomplicated logistical chain. Here, not a lot of improvements can be expected, as the box-like shape of the cargo units already makes stowage and handling relatively efficient. The logistical chain of paper, however, seems more suitable for improvements. Reducing labour for handling and damage can bring large cost reduction. Also, the inland transportation in western Europe, which is now done by lorries, is a cost item. Small changes in efficiency could bring major improvements.

Therefore this case-study focuses on the transport of paper. The following categories of paper and paper board products can be distinguished:

- *Newsprint*, which is thin, uncoated paper on which newspapers are printed;
- *Uncoated paper*, like copier paper and books;
- *Coated paper*, like paper for magazines and catalogues;
- *Wrapping paper*;
- *Kraftliner*, which is thick, rough paper for the production of corrugated paper board, paper board boxes, etc.

Paper is a vulnerable cargo, which is packed either on reels, or on pallets with boxes of sheets. The transportation of paper reels is and stays most important. This case-study focuses on the design of a new transport chain and specifically a new way of cargo handling for paper reels. Beside a new concept, this chapter also describes the process on how this concept was established and the creativity process that was used.

20.2 The existing situation

The present transport chain for paper reels from Finland to western Europe consists of five stages:

- Transport in Finland from the paper mills to the ports;
- Loading of the reels in the Finnish ports;
- Sailing of the ship between Finland and western Europe;
- Discharging of the reels in the western European ports;
- Hinterland transport to the final destinations.

Land transport in Finland

The land transport in Finland from the paper mill to the Finnish port is carried out by lorry. Most inland waterways are frozen during several months a year.

Loading in the Finnish ports

Because forest products form the major business of most Finnish ports, the harbours are relatively small. Because the amount of work is not constant every day, the number of workers must be adapted to the maximum amount of work. This makes stevedoring a costly operation. There are two solutions to reduce the handling costs:

- Separation of the stevedoring work from the presence of a ship; this makes it possible to have a continuous amount of work, every day;
- Automating of the cargo handling; this makes harbour workers more or less redundant.

Presently the paper reels are loaded according to one of the following three methods.

- Lift-on lift-off (lo-lo);
- Stowable roll-on roll-off (sto-lo);
- Roll-on roll-off (ro-ro).

In the lift-on lift-off method the reels are lifted on board from the trailer by a crane, see **Figure 1**. The reels are lifted by the crane by friction clamps or vacuum clamps. Friction clamps are a scissor-like construction that clamps around the reel. This type of loading is slow and the reels are easily damaged. Vacuum clamps suck themselves to the top of the reel. This way of loading is faster, but for every reel size a different clamp is required. If a lot different reel-sizes have to be handled, againl the friction clamps have to be used. Ships loaded by the lift-on lift-off method are often uncomplicated old-fashioned dry cargo ships.

The stowable roll-on roll-off method came into use to overcome most of the problems of the lift-on lift-of method. A roll-on roll-off ship is used. Platform cars are used to roll the cargo on board, where it is unloaded by a lift truck, see **Figure 2**. The platform cars or trailers can also be positioned next to a sideloader, from where the reels are distributed further by lift trucks.

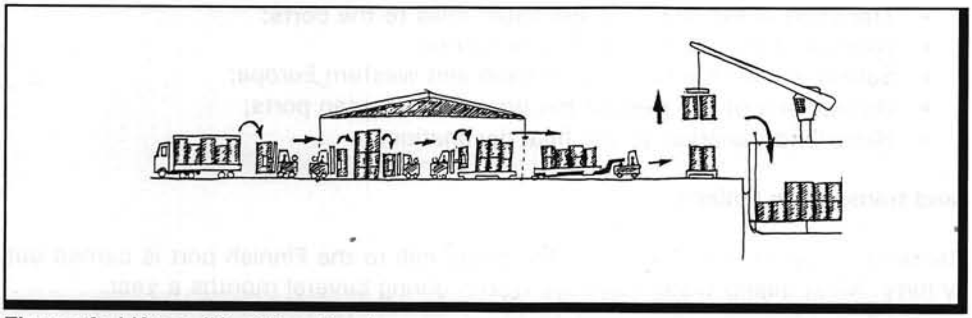


Figure 1: Lift-on lift-off method

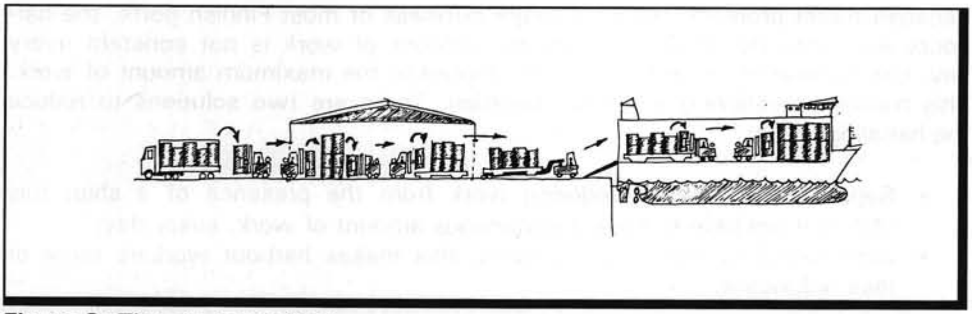


Figure 2: The sto-ro method

The roll-on roll-off method is a more universal system for transshipment. The paper reels are loaded on a trailer or cassette in the warehouse. Then the trailer is driven to the ship. Via a stern ramp the trailer enters the main deck. From here a hoistable ramp or lift gives access to lower and upper decks. The trailer is put into place, where upon the tug master disengages and drives back to the warehouse to pick up a new trailer. The trailer is lashed to the deck to prevent it from shifting (**Figure 3**).

Maritime transport

To achieve continuous flows, the shipping companies maintain liner services. Almost all ships that operate in these services are purpose-built ro-ro and sto-ro vessels. The rest is shipped by tramp vessels, usually lo-lo dry cargo ships. The liner services are usually on a weekly to two-weekly schedule, with often multiple ports of call in western Europe.

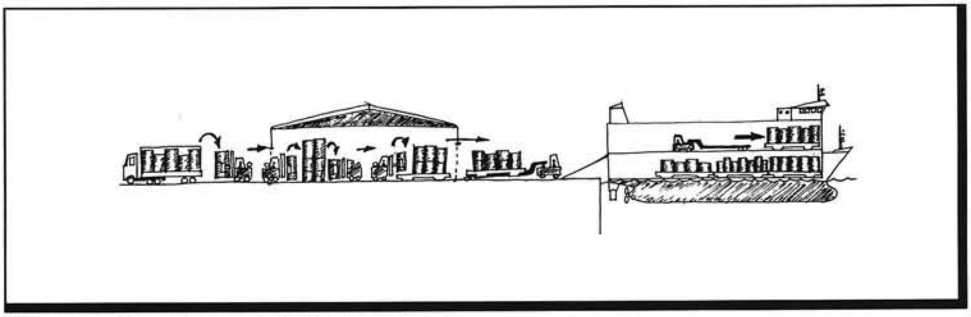


Figure 3: The roll-on roll-off method

Discharging western Europe

Ports in northwest Europe are usually bigger than the Finnish ports, a pool system of harbour workers can be created. A stevedoring company just pays for the time the stevedores have worked. The discharging operations are similar to the loading operation in Finland, but in reverse order.

Inland transport in western Europe

The paper can be transported from the port of discharge to the consuming industry, by three modes of transport: Road, rail and inland waterways. Lorries are most commonly used, because their high flexibility. It is, however, the most expensive way of transportation. Trains are fast, but not very flexible, because of the rails that are required. Inland barges are the cheapest form of transport. At present, inland waterways are hardly used for the paper transport. Low speed, little flexibility and the requirement of large batches of cargo are factors that make barges less attractive

20.3 Problem definition

The objective of the study is to come to a substantial reduction of the overall logistical costs by use of an integral approach. During the process of idea generation, the following ambitions will be attempted to achieve:

- The system must be simple. As little as possible mechanical and electronic systems will be used, in particular on board of the ship. These parts tend to break down, due to the moist and salty environment;
- Because of the vulnerability of paper reels, good damage preventing capabilities are required.

Value analysis shows the most profitable direction for innovation:

- Capital costs: Can be reduced by cutting down the time the paper spends in the warehouse;
- Loading of the seagoing vessel in the Finnish port: Handling costs can be reduced substantially by deceasing the labour content;
- Discharging of the vessel at western European port: Transshipment solutions from the Finnish port will also bring a benefit to the stevedoring costs in western Europe;
- Distribution western Europe: Here, major benefit can be gained, possibly by using inland waterways.

This chapter not only describes a new concept for the transport of paper reels, but also describes the thinking and creativity process foregoing the final solution.

20.4 Potential solutions

There are many ways to reduce the costs in the logistical chain. The following sections give some possible solutions.

Paper can be transported in unitised parcels. A distinction must be made between units meant to lower the stevedoring and warehousing costs, transshipment units and units that cover the whole logistical chain, intermodal units.

20.4.1 Intermodal unit

A quite obvious and dominating intermodal unit is the container. What can be learned from the container operations for the unitisation of forest products? For the transshipment unit, existing analogies are the barge carrier and the tug/barge system. Also, the concept of floating warehouses of Kværner Masa Yards is considered.

The intermodal unit is considered from the view of progressive abstraction. The question posed in this context is: "*What is the core function of a cargo carrying unit, when it is used for paper reels?*" The answer is: "*To connect paper reel to each other so that bigger units are obtained*"
This definition highlights a striking phenomenon. At the paper mills large reels are cut and rerolled into smaller reels. Putting these reels together into bigger units, means the reconstruction of the large reel. This seems to be a waste of energy. It appears much more efficient to transport large reels, and to do the cutting further up the logistical chain.

Giant reel transportation

At the end of the production line produced paper is rolled onto a giant reel, with approximately a length of 8 m., a diameter of 3 m. and weight of 30 tonnes. When the reel is full, it is transferred to another machine, where it is cut into smaller units with the dimensions required by the printing houses. The question is: "*Can the paper be cut later in the chain?*" Then the cutting has to take place as far up the chain as possible, i.e. in a west European warehouse. From here the paper can be distributed in small parcels.

The transport of the giant reels has some complications. Transport in a vertical position is impossible. Also, the reel would deform. If the reels are transported in a horizontal position, they tend to become pear shaped.
Inland transport in Finland is carried out by rail or road. The maximum width of a lorry is 2.6 m. As forest products industry in Finland is of major importance, possibly dispensation can be obtained to move reels with a larger diameter. If this is not possible, the reels have to be adjusted to the rules. This means the diameter of the reels have to be cut back to a bit less than 2.6 m. The weight of the reel will then decrease to 21 tonnes.

Cradle container

A special cradle for the transport of giant reels can be developed. The upper part of the cradle has to be from paper friendly material to reduce damage, for example multiplex. The substructure is a cassette, fitting in the rolux system.

To get the cradle in a standard 40 ft. container the bottleneck is the heigh of the door opening. This height is 2.26 m., which then is the maximum height of the reel cradle. High cube containers are 0.15 m. higher.
A 40 ft. container cannot be fully used, since the length of the reel, 8 m., is significantly less than the inner length of the container, 12.01 m. A 30 ft. container would be more suitable, but they are less used.

20.4.2 Transshipment unit

The next step beyond the intermodal unit, is the transshipment unit.

Barge carrier

A barge carrier system makes the transshipment independent of port facilities. This system provides a transshipment unit without the need for an expensive quay-side logistic harbour function. When inland waterways are used, the barges can be used to cover a larger part of the logistical chain than just the transshipment. The barges are transported in a tug/barge combination.

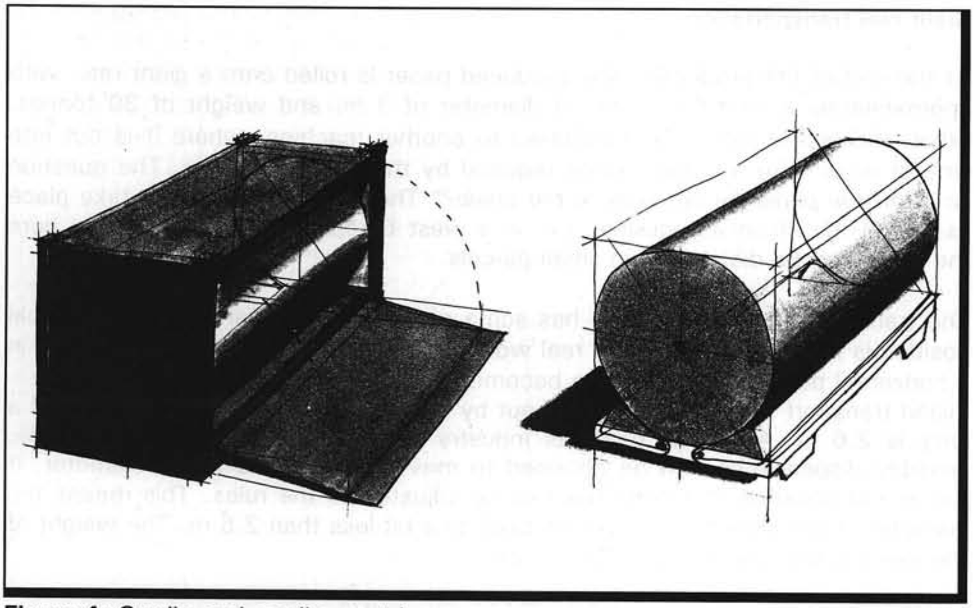


Figure 4: Cradle and cradle container

This method reduces the port time of seagoing vessels because of the fast transhipment. It is independent of port installations, and loading and discharging of the barges does not influence the port time of the carrier. Disadvantages are the expensive equipment on board the ship and the need for various sets of barges, which requires large investments. Also, the payload is very low in relation to the total deadweight because of the excessive packaging. Several barge carrier systems have been developed in the past, but none of them was a great success. This will probably also be the case for the transport of forest products.

Floating warehouse

The floating warehouse concept is developed by Kværner Masa Yards Technology. The initial idea was generated by use of a creativity technique, in which the following question was asked: "*When considering the logistical chain, what would happen if one part was kept out?*" The stevedoring was kept out of the forest products chain. The idea was to use floating warehouses in the ports.
When the forest products arrive at the Finnish port, they are not put into storage in a warehouse on the quay, but directly loaded into a floating warehouse. this can be a warehouse on a pontoon, a barge or even a ship. At regular intervals, these warehouses are shipped to the European distribution site, no matter if they are completely full or not.
By maintaining a regular schedule, a good degree of service can be accomplished. At the European port, the distribution takes place directly from the floating warehouse, without transshipment.

Since the use of ships as warehouses would be highly inefficient, because of the extreme high port times of the high value ships, lighters function as warehouses. These lighters can, for example, be transported by heavy lift dock ships (**Figure 5**). This would provide and ultimate kind of barge carrier. However, heavy lifts ships transporting floating warehouses has some major disadvantages:

- Operations of a heavy lift ship are too expensive to start a competitive service in the low freight rate forest products market;
- The floating warehouse is carried by the heavy lift ship, so it does not need to withstand the waves by itself. However, the movements of the ship imply large forces, so the warehouses require a heavy construction after all.

Another way of using the floating warehouse system is to use a tug/barge system.

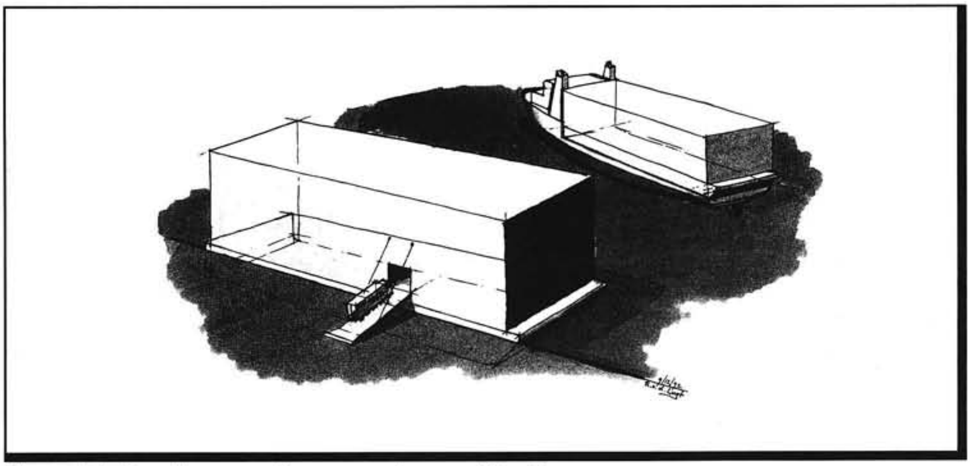


Figure 5: Floating warehouse on heavy lift ship

Tug/barge systems

A tug/barge system is a kind of barge carrier system. The principle difference is that during the sea journey the barge is not protected and carried within the hull of the seagoing ship, it floats by itself. The tug is used as propulsion unit only. A second difference compared to the regular barge carrier is the number of barges transported. For a tug/barge system this number is limited to one. Some existing and none existing tug/barge concepts are described in **Chapter 17**.

The barges can be transported by river to the consumer area. Then the logistical system would look as follows. The reels are transported from the paper mill to the Finnish port by truck or train. At the port, they are directly stowed in the barge. The barge remains in the port for a fixed period of time. Weekly, or maybe two-weekly, a tug delivers an empty barge and picks of the full one, even if the barge is not totally full.
In western Europe the tug drops the full barge and picks up the empty one, which is transported back to Finland. The warehouse barge remains at the quay. Lorries load the paper directly from the barge and transport it to the client.

20.4.3 The shape of the current paper unit

The paper unit that is used most often is the paper reel. Using the creativity method of progressive abstraction, the following core questions were defined:

- "*What is the shape of a paper reel?*"
- "*What advantages and opportunities does this shape bring?*"

The paper reel is a cylinder. The most important quality of a cylindrical shape is that it has the ability to be rolled. This characteristic is elaborated further. How can this be introduced into the logistical chain?

Possibilities for transshipment

To construct a bulk-like transshipment system, instead of using conveyors, the forces of gravity can be used. Inclined paths to and from the warehouse are created. The reels roll over these tracks to the ship at the quay. It is possible to have the paths take care of the warehousing function, in the form of short term buffer stocks. Instead of the reels rolling on by one, a whole ship's cargo can be loaded onto the path in advance. When the ship arrives, the reels only have to be released to roll into the ship.

An analogy is a can dispenser. Those are machines that distribute cans as seen in cafeterias, gas stations, etc. The cans are stacked in rows on inclined shelves. When someone wants a can, he pulls the small hatch open. A cradle bearing a can comes out. When the hatch is shut, the cradle slides back and because of the inclination of the shelf, the next can rolls onto the cradle (**Figure 6**).

The same principle can be used in a ship. If the transshipment is carried out through the stern, the movements can be kept in a longitudinal line. The complex system with cradles can be avoided. The essence of the analogy is that just like the can dispenser, emptied spaces are filled up by use of gravity and the roling capabilities of cylinders.
This concept can be implemented in the warehouse. The reel carrying paths are given a small slope. If the first reel is taken out of the path, when it is loaded

onto the ship, the entire line of reels will shift one place, so that the next reel comes into position to be loaded (**Figure 7**). A series of problems are with the system of rolling reels:

- If a line of cylinders is pushed forward, friction problems arise. Succeeding reel will have the tendency to turn counterwise. High friction between reels, or between ground and reel imply high wear of the outer surface of the reel.
- Due to the friction a relatively large inclination is required to initiate the rolling of the reels;

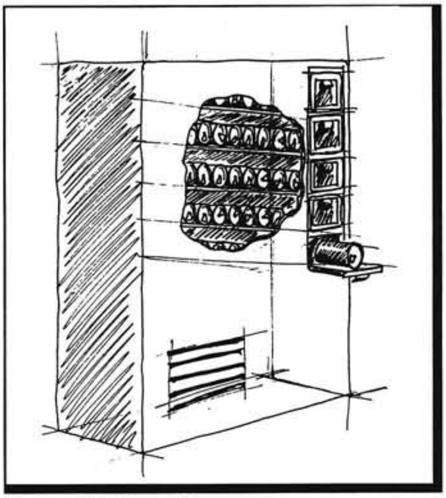


Figure 6: Can dispenser

- The paper reels have a lot of different cross sections. Because of the uneven division of forces, the large reels will be pushed out of line, on top of a smaller reels;
- If not guided, the reels will probably not roll in an exactly straight line, due to inequalities of reels or track.

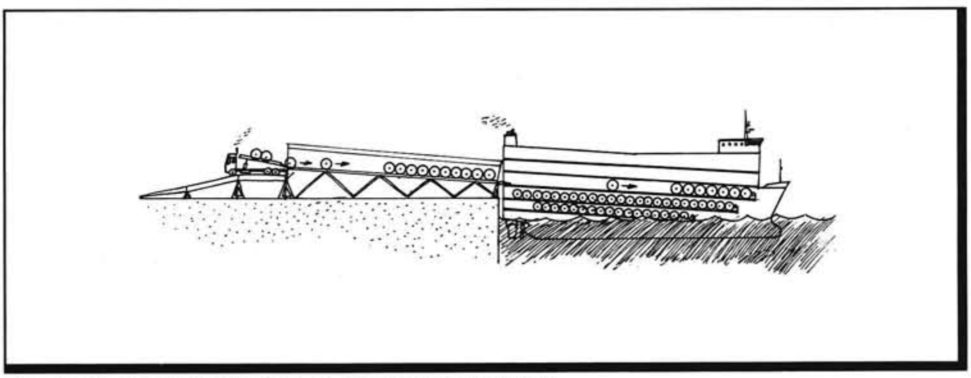


Figure 7: Implementation of the can dispenser

Reels-on-Wheels

One solution to avoid the complications of rolling cylinders is to put a steel bar inside the tube of the reel, put it on wheels and guide it on rails. A problem that arises here is the danger of askew sliding of the reels with axle. To cope with this problem, small, uncomplicated wheels can be connected to the axle. From this moment on....

The 'Reels-on-Wheels' system is born

The internal structure of the hold will only consist of a steel framing with rails over the entire length of the cargo hold. The rails will also serve as longitudinal stiffeners. **Figure 8** shows the cross section of a reel on wheels.

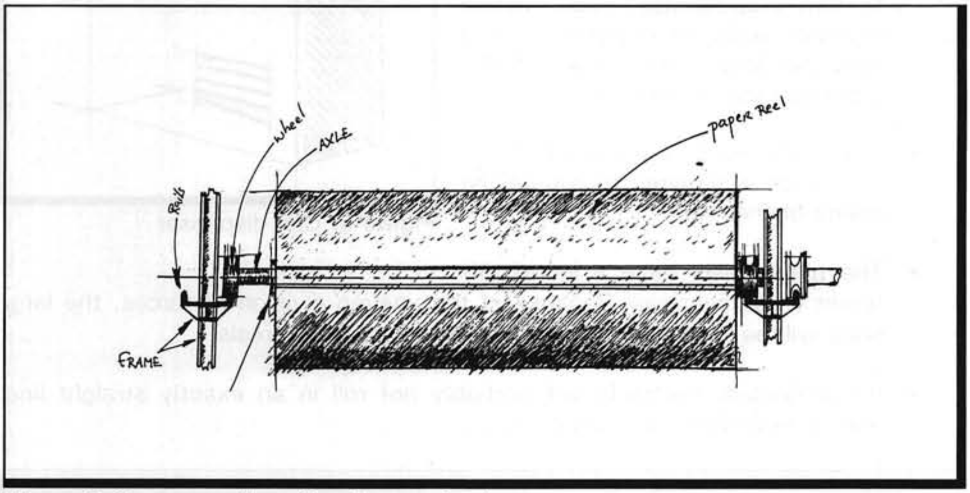


Figure 8: Cross section of reels on wheels

20.4.4 The logistical chain of Reels on Wheels

An entire chain using the Reels-on-Wheels system is created, from the paper mill to the printing house, including the use of barges on the inland waterways. This way the distribution can take place close to the centre of the market area.

Paper mill

The axle with wheels are put on the reels when they come out of the production process. Then they are directly, by use of the force of gravity, rolled into lorries, so that the warehousing function at the paper mill is eliminated.

To be able to load the reels longitudinally into the lorries, the length of the axles cannot exceed the maximum width of the vehicle. In Finland this is 2.6 m.

Therefore, the width of the reels must be smaller than 2.5 m. It this is not possible the truck must be loaded transversely.

Finnish port

At the quay, the truck discharges its cargo into the warehouse, which consists of a number of inclined rail tracks. This warehouse is situated directly to the quay. The reels roll down the track, so that the warehouse is automatically filled up. There are a large number of different constructions possible, of which one is shown in **Figure 9**.

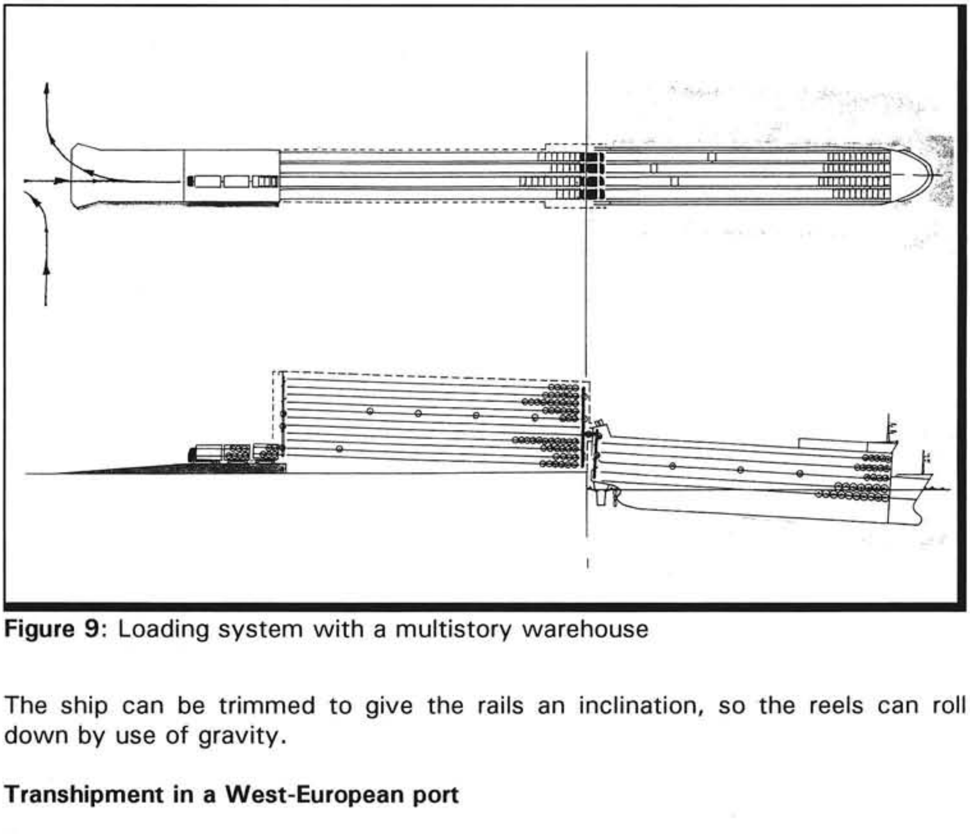


Figure 9: Loading system with a multistory warehouse

The ship can be trimmed to give the rails an inclination, so the reels can roll down by use of gravity.

Transhipment in a West-European port

At the West-European port, the vessel can discharges its cargo directly into an inland barge. In that case the inland barge must have the same capacity as the seagoing vessel. The use of inland barges requires an additional transshipment, compared to a barge carrier system. However, the barge can be very simple and light in construction. It does not have to withstand acceleration forces due to the ship's movements at sea. When a fast, labour extensive way of transshipment is used, this method is preferred.

Inland transport

The barge is pushed by inland waterways to the distribution port close to the centre of the market area. The barge is moored, the tug disconnects and takes an empty barge back to the seaport. The full barge is used as a floating warehouse. From here, the lorries that take care of the short distance distribution are loaded.

20.5 The ship design

The initial idea was to develop a cellular cross section of the hold. Every pair of rails is separated from the others by a horizontal construction member. To optimise this cross section, other configuration had to be generated. In order to be able to do this, information on the dimensions of the mix of paper reels is required.
There is a large variety of dimensions of the reels. Therefore, a very flexible way of handling and stowage of the reels is required. The paper reels were classified in a number of groups. The group with reel diameters of 990-1040 mm. is by far the biggest. The 1190-1240 mm. group is also significantly larger than the rest. Together they make up two third of the total volume. The cross section of the hold will have to be optimal for these two groups and also acceptable for the remainder.

20.5.1 Cross section 1 - One per rail

The initial idea for the hold configuration was one rail per cell. The hold is divided by horizontal and vertical structural members, so that the cross section is divided into cells. Each cell contains one rail on which reels can be loaded.

An important disadvantage of this structure is that, if all reels have to be accepted, the height of the cells (and therefore the spacing of the reels) will have to be very big. This implies a very low use of the available cargo space and the vertical location of the center of gravity is very high. This may give stability problems.
Using different cell height can make the hold more efficient, but it will decrease the flexibility of the hold. Another option is to reject all extreme reel sizes that are quire rare. This, however, is not a real innovative solution. There must be better ways.

20.5.2 Cross section 2 - Three rails per cell

The required height for one reel will have to be reduced, without a decrease in flexibility. This can be done by increasing the height of the cells, which means reducing the number of transversal stiffeners, so that more rails can be put into one cell. This way, large reels can be placed into the cell. The cell is then filled up with smaller reels in the remaining rails. If there are no fitting reels, the remainder of the rails stays empty

For this system a minimum of three rails per cell is required. If it is preferred to us more rails per cell, an odd number of rails is needed, so that a small and large reels can be alternated. According to a simulation model that was made, the optimal rail spacing is 1300 mm.

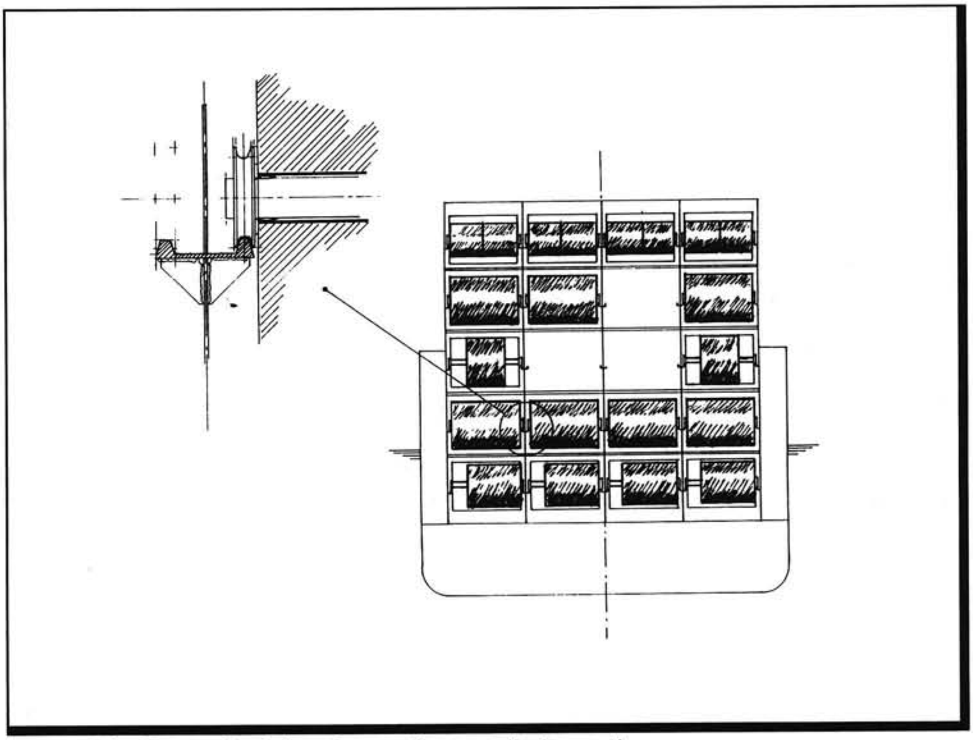


Figure 10: One cell of the three-rail per cell alternative

20.5.3 Cross section 3 - Multiple rails

The two previously described options do not have much flexibility. The hold will not be used optimally. That is why it was necessary to find new ideas to solve this problem. The idea that came was to produce a cross section with exaggerated flexibility: Put movable rails in the hold. That way, the hold would become very flexible. However, movable rails imply a complex construction. And mechanic constructions aboard of a seagoing vessel imply high risk of malfunction and lots of maintenance. Therefore the idea did not appeal too much. However, if the rails cannot be moved, another possibility to get a similar result is to put more rails into the hold, one set for 1040 mm reels and one for the 1240 mm reels. This way the loader is free to choose which set of rails to use. The flexibility of the system increases. But, in this case, some rails have to be placed so close to each other that no wheel would fit in between.

With a small amount of extra rails, a system with a standardised, very small, rail spacing can can be achieved. The hold would not be totally optimal for the two largest groups any more, but better for the overall results, and the flexibility is improved considerably.

What is the maximum amount of rails that can be put into the hold? This amount is determined by the minimal rail spacing required. The minimum rail spacing is the distance, needed for the wheels, the cross section of the rails and the required safety margins. The estimated minimum rail spacing is 218 mm. For strength reasons the hold is equipped with one transversal stiffener (**Figure 11**).

20.5.4 Cross section 4 - multiple rails, no transversal stiffener

To get even more flexibility, also the last transversal stiffener is removed. This gives ultimate flexibility, at a cost of heavier construction, and the required width for the constructive members will be quite high. But, by selecting the appropriate rails, every reel can be loaded efficiently, see **Figure 12**.

20.5.5 Evaluation of the different alternatives

The various alternatives are evaluated by giving grades on the most important decision parameters. These are:

- Flexibility — The simplicity with which the hold is loaded;
- Weight — The weight of the construction;
- Volume — Space required for the construction, split into vertical and transversal space;
- Opinion — Personal opinion based on the values of the previous attributes.

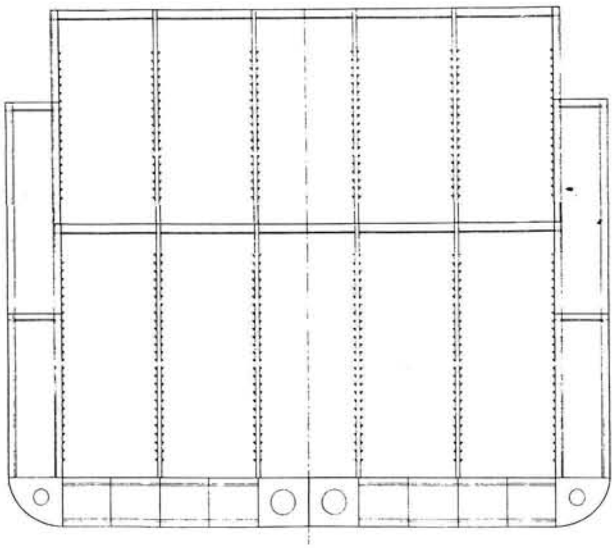


Figure 11: Cross section 3

Table I shows the evaluation of the cross sections. The multiple rail options provide the best opportunities. The alternative with no transversal stiffener is given the most characteristic grades. this might be a signal for large opportunities provided that the negative issues are dealt with.

	Flexibility	Weight	Transveral space	Vertical space	Opionion
Cells, one rail	--	+	+ +	--	-
Cells, three rails	-	+	+	-	- +
Multi rails, one stiff.	+	+ -	+ -	+	+
Multi rails, no stiff.	+ +	-	-	+ +	+

Table I: Evaluation of the cross section

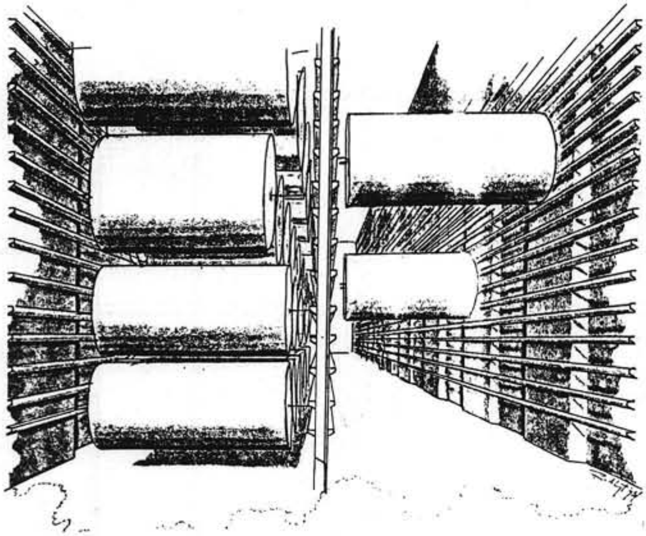


Figure 12: Artist's impression of cross section 4

Figure 13 and **Figure 14** show the design of the reels on wheels carrier.

20.6 Cost reduction

It is very hard to give a good overall cost estimation. A rough estimate is given for the transshipment. No estimate is made for the sea transport, for it is too uncertain what the costs will turn out to be.

For the transporter, transshipment are on a level of about NLG 35.- per tonne, By introducing the Reels-on-Wheels system this can be reduced to about NLG 12.50 per tonne. In Finland the transshipment costs can be decreased by an even larger percentage, for labour costs there are a more dominating factor. The estimated cost reductions are shown in **Figure 15**.

20.7 Evaluation of the innovation process

At the end of the first phase of the study, a view was made on what the innovation process should look like. This schedule was not followed very closely, for in a creative process it is not wise to follow a predetermined path too strict.

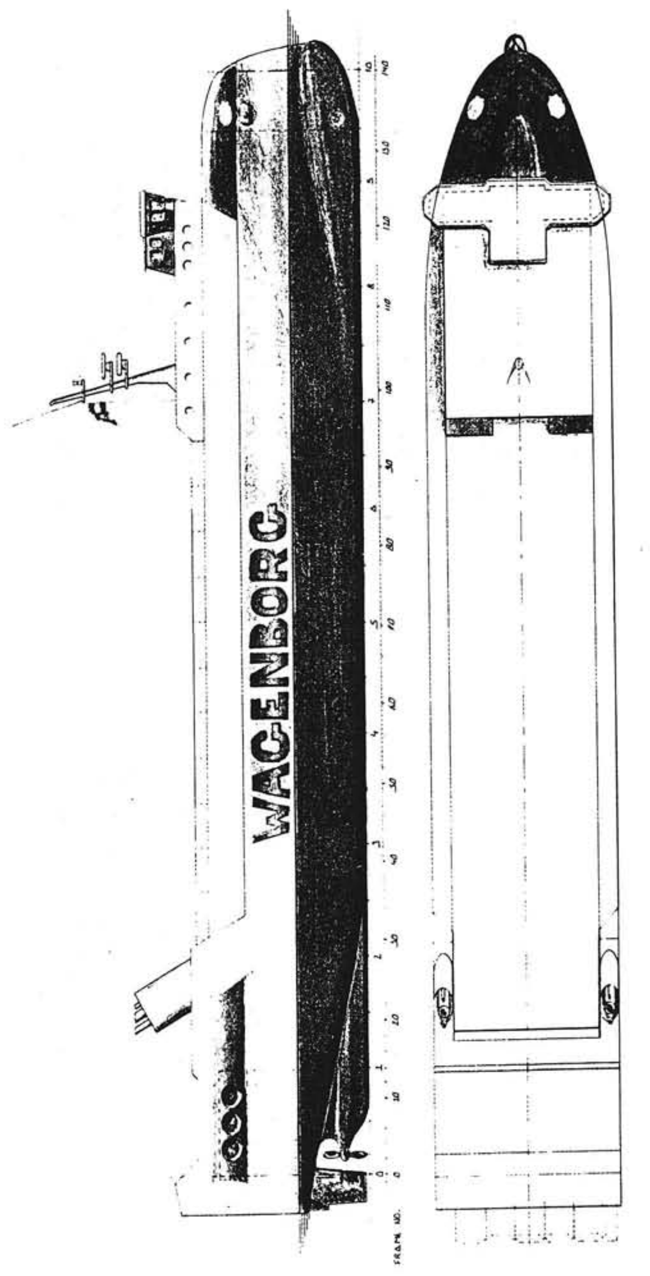


Figure 13: General arrangment, side and top view

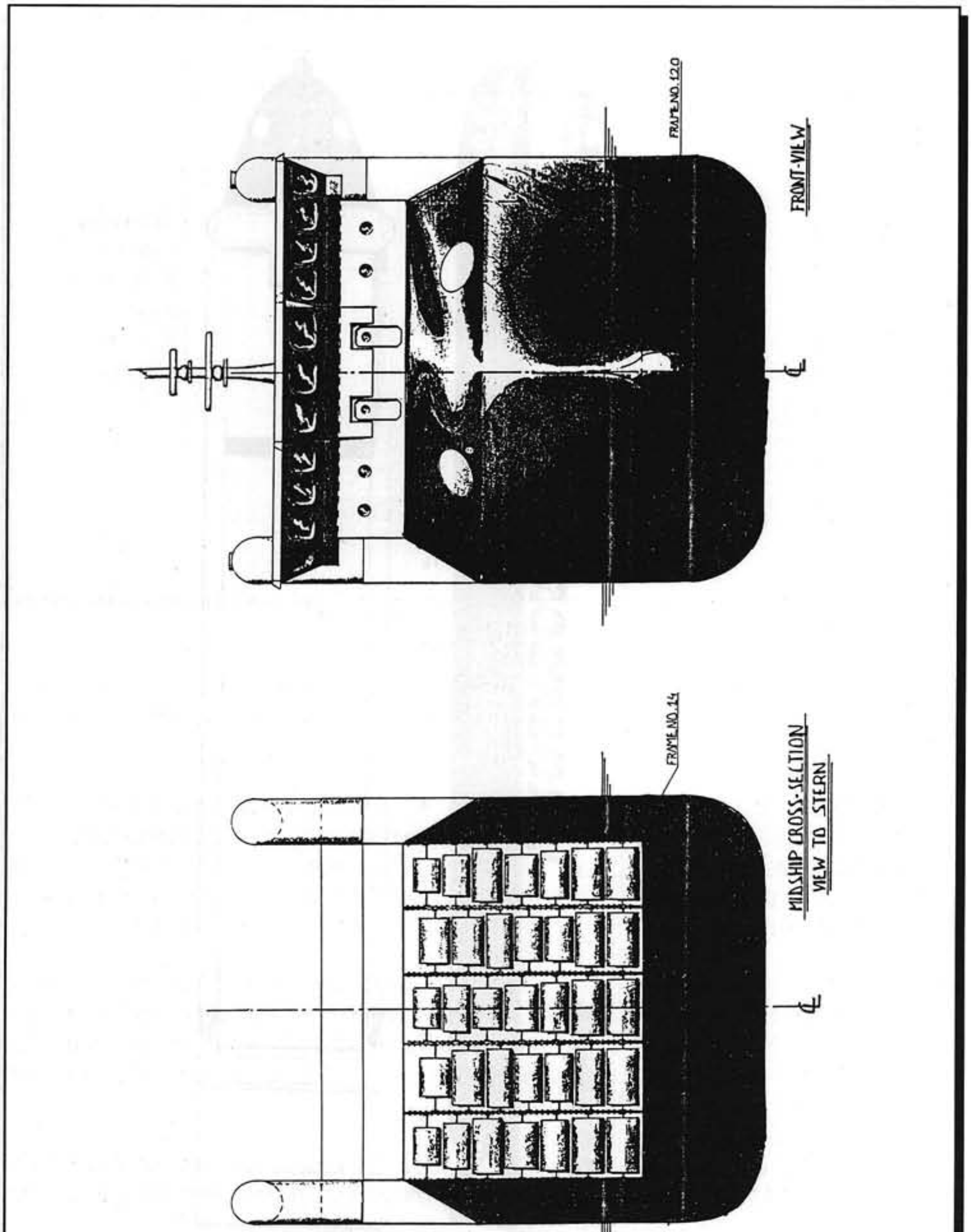


Figure 14: General arrangement, front view and cross section

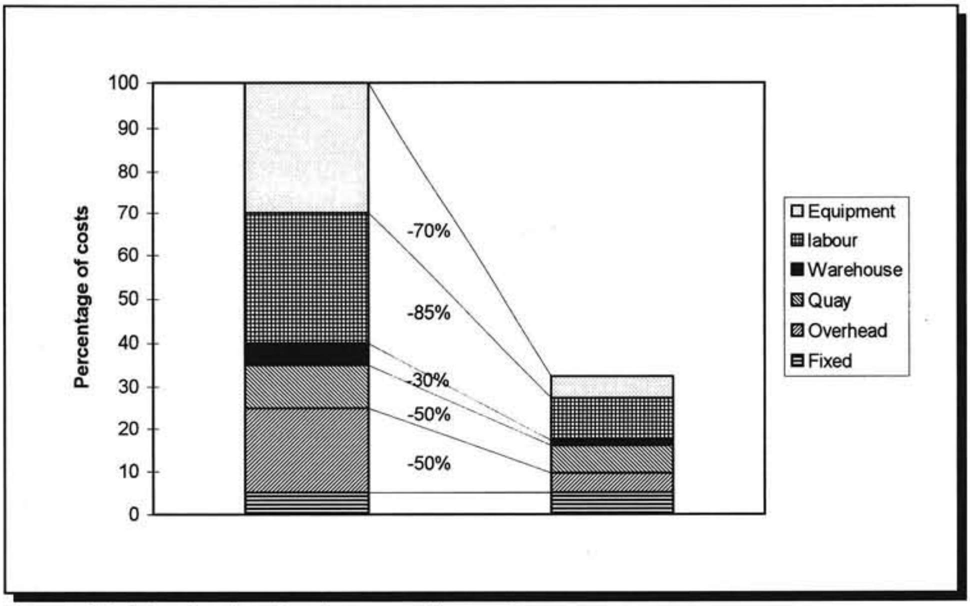


Figure 15: Total reduction in transshipment costs

Then, the possibility of looking for better ways is taken away. It will be of interest to notice the differences in the planned and the actual second part of the innovation process.

At the start of the second phase, a more detailed strategy was made for the elaboration. The bottleneck analysis and the part of solving the bottlenecks were postponed. The bottleneck analysis was transformed from a specified block function in the process into a 'notebook' function. When a bottleneck appeared it was noted and then put aside, if not essential for the design process.

This way, the negative input that comes from the bottlenecks can be moved to a later part of the process, so that the innovation process is not affected in a negative way. However, if the bottleneck that is encountered, blocks the continuation of the design process, the bottleneck is directly taken care of. Such bottlenecks can trigger new ideas.

The smaller bottlenecks are noted. If an idea to overcome such a bottleneck arises, this is also recorded. Neither these minor bottlenecks, nor the generation of solutions are allowed to obstruct the main innovation process.

The idea of the Reels-on-Wheels is worked out further. At first a 2-dimensional view of the hold is optimised by producing a simulation program, to determine the optimal vertical spacing between the rails. Decision parameters of the simulation are the load factor, vertical centre of gravity and the number of reels that cannot be loaded. The dimensions of the supplied paper are generated by a randomised distribution of paper reels. After the optimal two dimensional configuration is decided upon, the hold is given a third dimension. The three dimensional construction is considered.

Then, the box shaped holds needs to be put into a vessel. Thus, a hull is shaped so that the hold fits best. This vessel is elaborated further to meet the special demands, e.g. trim ballast capacity, etc.

When the development of the Reels-on-Wheels carrier is completed the vessel is put into service. The liner service is determined. This provides the basis for economic evaluation. Then, after the essential service is given sufficient shape, some important details are considered, as well as the bottlenecks. The project is concluded by an economic evaluation to weigh the benefits and disadvantages of the new system.

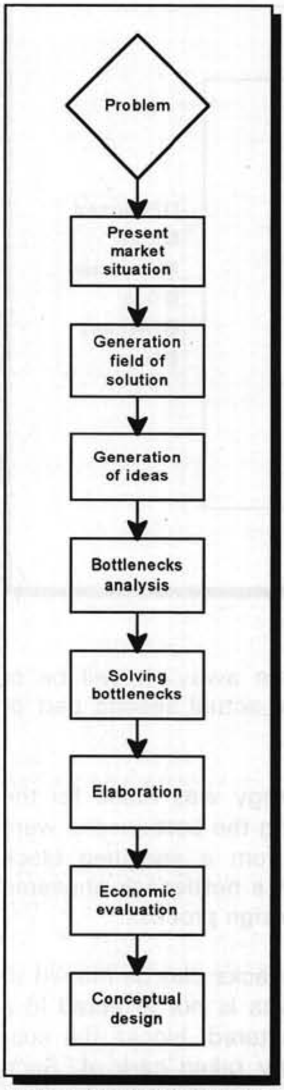


Figure 16: Initial view on the innovation process

As mentioned earlier, the planned process was not followed. In fact, the real process turned out to be quite different. Instead of a process with divergent and convergent phases, it turned out to be more like succeeding creative and engineering phases feeding each other. The creative part is not the only phase from which new ideas are generated. The engineering part, in which calculations are made, brings deeper insight in the actual requirements. This way preconceived opinions are eliminated and the field of view is widened.

E.g. transversal stiffeners in the hold were expected to be required to given the construction of the hold sufficient strength. Ideas were generated with this in mind. And these ideas did not turn out to be optimal. Rough calculations were made of the requirements in strength of the construction. A hold of the Reels-on-Wheels carrier without any transversal strengthening appeared to be feasible, which lead to a satisfactory solution. This time the calculating, engineering part was the originator of a new idea, followed up by a creative part to give the idea more shape.

This way of thinking is used a number of times, generating the idea and then diving into the calculations that apart from backing up the idea brings up new ideas as well.

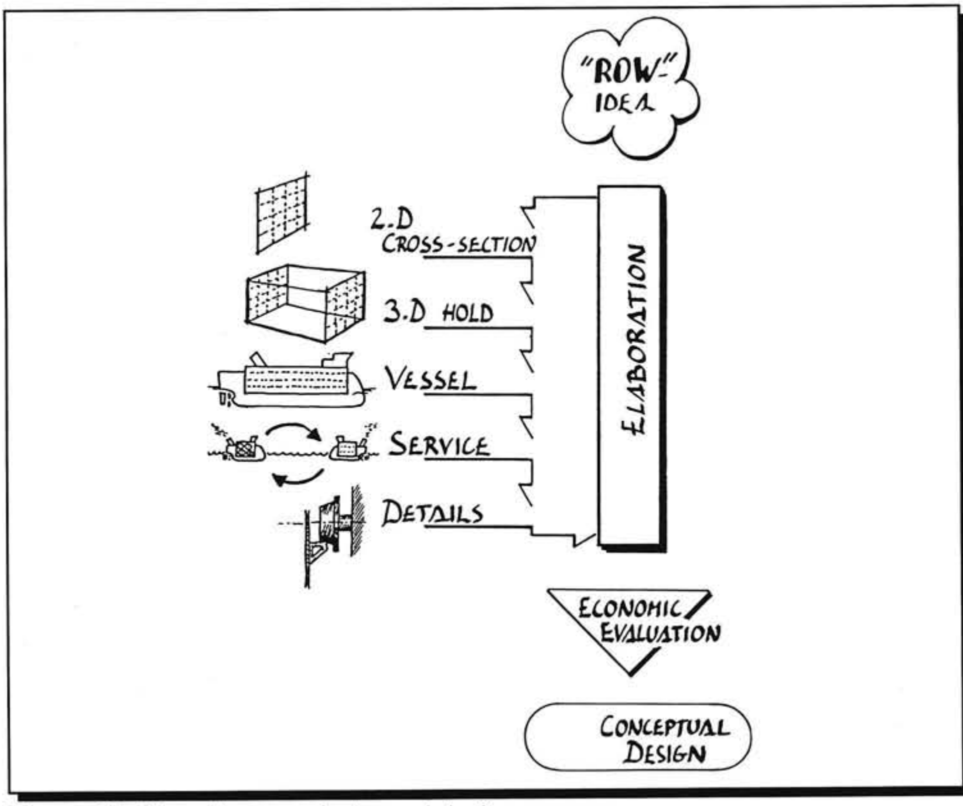


Figure 17: Flow diagram of planned design process

Similar to the creative/engineering contradiction that is used to stimulate the process, also the perspective is changed all the time. Sometimes the perspective is wide, globally handling things. As the process gets stuck at this level, the perspective is lowered to let the process go more into detail. If the problem is solved, the level is raised again.

A couple of times, searching an expert opinion opened up new ways of thinking. If the process is in a deadlock, another person may have a different angle of perspective, which might bring new opportunities. And, the expert opinion gives a view on what is possible, so that the constraints can be adjusted.

In the first phase the process had a parallel (divergent/convergent) character, firstly generating a number of independent solutions and then weighing those against each other. In the second phase most ideas were generated in a serial sequence, the constraints and benefits of the previous idea triggering the following idea.

It appeared that, if the direction is not decided upon yet, if the field of view is wide open, the divergent/convergent way is most applicable. This way the opportunity of the wide perspective is fully used, giving room to all possible ways to grasp the problem. In the second phase however, the perspective is deliberately narrowed, so that a small range of solutions can be elaborated to a sufficient extent. A serial approach, one idea following up on another, gives the best coverage of the small area.

Figure 18 shows a flow diagram of the actual innovation process, as it was experienced.

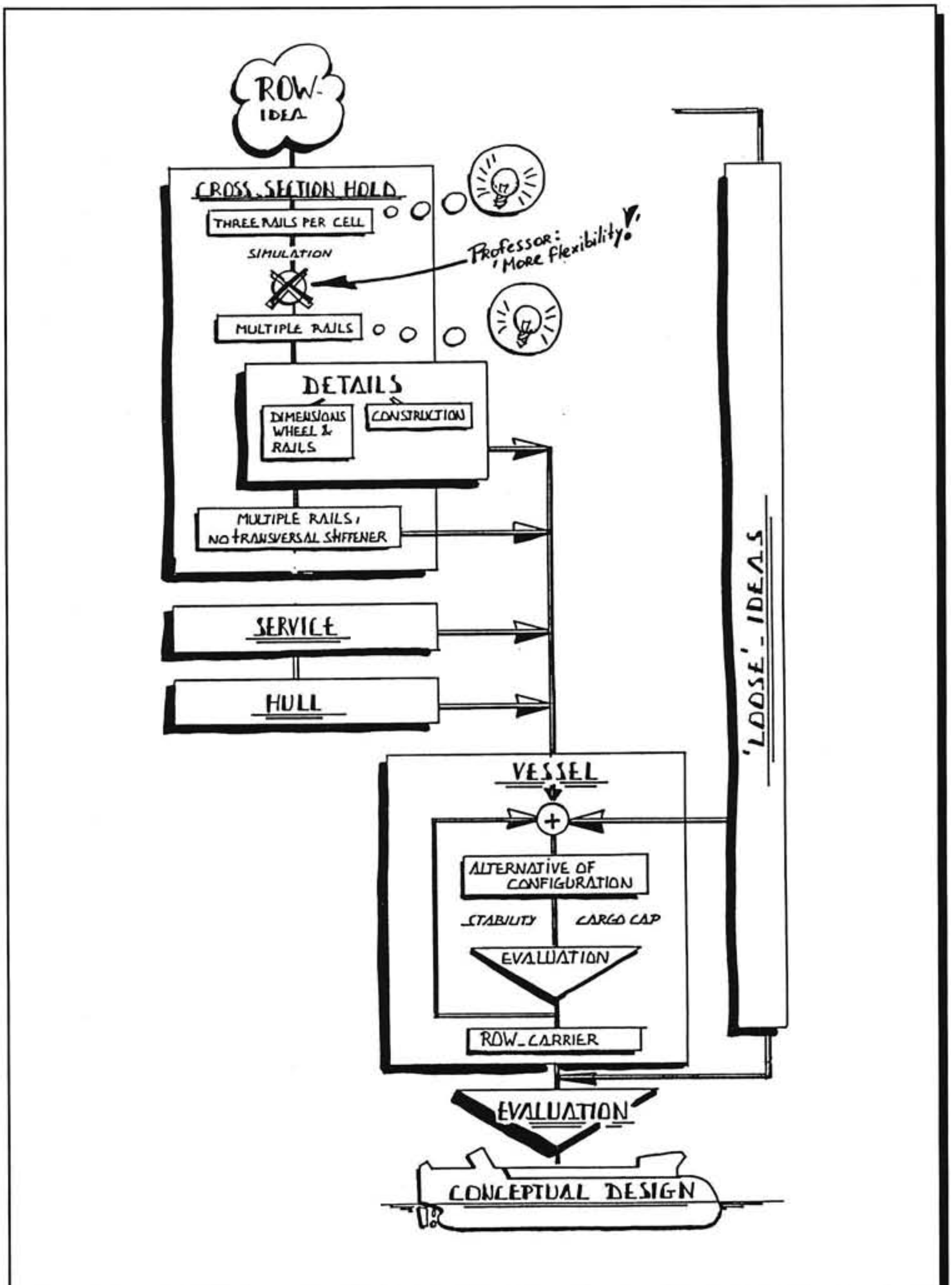


Figure 18: The actual innovation process

CHAPTER 21: INNOVATION IN SHORTSEA SHIPPING

21.1 Critical success factors for shipping

Competition between seaborne and land transport is presently very limited in volumes and types of commodity. Only high-value general or break-bulk cargo packed in unitloads like the maritime container or the swapbody competes in shortsea shipping with road and rail transport.
In order to understand the reasons why this is the situation, the critical success factors will be analysed in this paragraph. The following critical success factors will be examined in more detail:

- Transport (transit) time;
- Transport costs;
- Frequency and flexibility;
- Reliability;
- Customer (shipper, receiver) satisfaction;
- Environmental impact;
- Political acceptability.

Although most of these factors are related, they will be discussed separately.

Transport time

Transport time is a crucial element in any discussion about shortsea shipping. Extra transport time in comparison to land transport is hard to avoid, which is unattractive to most shippers. On the other hand, if a considerable cost reduction can be realised in combination with an acceptable and predictable increase in time there could be an opportunity to attract cargo from the transport market. The increasing value of time makes transport time a dominating critical success factor.

Transport costs

A low freight rate has to counterbalance the relative increase in transport time. In order to reduce unit costs, the variable costs have to be controlled and reduced. In general, reducing the variable-cost part of a total cost figure requires investments, which will result in higher fixed costs. An optimal balance between fixed and variable costs should give the lowest unit cost.

Frequency and flexibility

For a coastal and shortsea shipping system it is a major challenge to offer flexibility at the highest possible level. The flexibility a road hauler can offer is very hard to match. Frequency of sailings is a major critical success factor. Offering only a weekly sailing is sure to fail to attract the attention of shippers and receivers. A daily departure is a prerequisite for a competitive shortsea shipping system. The added advantage is that ships are allowed to call on the ports in the weekends, while road transport is often prohibited to drive during the weekends.

Reliability

From a shipper's point of view today's sea transport is sometimes the less reliable form of goods transport, when compared to transport by road or railway. A shipping organisation is faced with a bigger number of potential delay factors than the other two modes, causing a low reliability image. There are, however, effective means to get in control of some of the delay factors while others can be prepared for, in the best possible way.

Customer satisfaction

Shortsea shipping should offer the same attraction to customers as land transport. This can be achieved by offering a comparable level of convenience, which means taking care of the complete transport from the first moment a customer calls for a transport until the final delivery at the receiver's end.

Safety

From a shipper's point of view, safety of transport means the arrival of the goods in proper condition and the avoidance of liability problems. Society interprets the safety of transport in terms of accidents and damage to nature. Safety is a subject with many conflicting interests.

Environmental impact

From an energy consumption point of view, ships perform better than lorries and trains while, especially on board of ships, modern technology can be used effectively for the purification of exhaust emissions. Sea transport already is the most environmentally friendly form of transport today and it also has a good potential for further improvement.

Political acceptability

Increasing transport capacity by expanding roads and railways requires heavy state investments and it is not an environmentally friendly solution and often requires a lead-time of decades rather than years.
If shipping can prove to be a competitive alternative in terms of time, costs, reliability, flexibility, and customer friendliness it would be of great interest to both society and the manufacturing industries if politics would express the will to develop a competitive shortsea shipping system.

Conclusions

The evaluation of the critical success factors leads to the conclusion that measures which minimises shore labour (stevedoring) have the largest potential for improving the competitiveness of shortsea shipping.
Time independent methods for the ship/shore transfer of cargo are expected to lead to the most significant time and cost saving improvements. Automation of the respective onshore and the onboard cargo handling processes will contribute to further reduction of time and costs. New applications of existing technology in combination with innovative developments are necessary to realise such time and cost saving cargo handling systems.
Once a time-independent and automated cargo handling system has been developed the design of an advanced vessel can be initiated, incorporating all other cost, time and environment saving features it should offer. The technical feasibility of such a system is dominating although the total competitive strength very much depends on the restructuring of the goods transport industry as a whole.
In conclusion; the key-critical success factors of a competitive shortsea shipping system are:

- Time-independent cargo handling;
- Employ shore labour from 9h/17h only;
- Automated cargo handling on board, at the terminal;
- New agreements with third parties;
- Develop E.D.I. and central booking;
- Develop traffic control and management;
- Environmental and social costs increases of other modes.

21.2 Cargo potential

As a subject for this case-study Sweden is chosen. The coast line of Sweden is very long, approximately 2000 km. from the top of the Botnic Gulf to the most southern tip at Ystad. It is, therefore, ideal for shortsea shipping.

Any beautiful system fails without an adequate cargo-base. Therefore first the potential for a shortsea shipping system is estimated.

The shortsea shipping system will operate on the bulk and break bulk cargo market. The cargo potential system consists of parts of the markets of road and rail transport en the coastal shipping market. The cargo share that lies within reach of the system. The system is especially suited for the higher distances. **Table I** gives an overview of the cargo that may be transported by the system.

Total market size (transferable goods)	Volume (tonnes)	Volume (tonnes)	Average haul
Road cargo northbound	1,261,000		264
southbound	1,132,000		264
		2,393,000	
Rail cargo northbound	800,000		575
southbound	1,500,000		575
		2,300,000	
Shipping discharging	4,013,000		
loading	3,343,000		
		7,356,000	
Containers	65,123 TEU		
Total Market Size	65,123 TEU	12,049,000	

Table I: Cargo potential for the shortsea shipping system

21.3 Ports of call selection

The system requires a number of ports to load and discharge cargo. These port must be chosen very carefully, as the number and locations determine the workability. The selection procedure is divided into two steps:

- First, a selection is made to select all applicable ports out of all available ports along the east-coast of Sweden;

- Second, from all selected ports, the optimal ports of call configuration is chosen.

The selection of all applicable ports is based on the following criteria:

- Minimum port dimensions;
- Accessibility of the port;
- Location of shippers and receivers.

Minimum port dimensions
The minimum dimensions of the vessels depend on the ice-conditions in the Baltic area, the size of the cargo-flow, speed of the vessels and service level. It must be possible for the ship to enter and leave port easily, leaving sufficient space for manoeuvring and mooring. It is important for breaking ice that the ship has a minimum size. The minimum size is a length of 110m., a breadth of 19m. and a draught of 5,75.

Accessibility of the ports
The coastline of Sweden is very irregular. This irregular coastline provides many natural shelters an ports. However, not all these ports are easily accessible from the seaside. The accessibility of the ports from the land side must be provided by a reliable infrastructure, which at least consists of an extended road system.

Location of shippers and receivers
The locations of shippers and receivers is evenly divided along the coastline. No ports are in special favour or can be left out of consideration.

The selection of the ports of call from all suitable ports is done according to the criterion that the total transport costs must be minimized. A reduction of total transport costs can, among others, be obtained by reducing the land transport. Also the sea transport must be taken into consideration.
In contrast to the land transport costs, which increase when the number of ports is decreased the sea transport costs decrease when less ports are serviced

A shuttle port service should serve as a cargo distribution center for the hinterland transport and as a transfer spot for cargo that is transported by the vessels. The level of service that a port can offer depends in the first place on the availability of cargo in the port itself and in the second place of the availability of cargo within the service area of the port. The service area of the port is defined by an imaginary service radius. With this service area it is possible to make an astimate of the amount of cargo available for each port. Within a certain service radius all the available cargo must be transported to this port by land transporters.

21.4 Round-trip exploration model

The shipping service depends on a number of variables. A round-trip configuration must be selected. In order to present these in a systematic way, a round-trip time exploration model is made.

There are six important variables:

- Sailing distance;
- Calling interval;
- Box capacity;
- Number of ships
- Average box handling time;
- Sailing speed.

These variables are all dependant on each other and can be formulated in a number of equations. In order to gain insight in the six variables of the round-trip model, and the sensitivity of the variables to changes, the variables are changed systematically. Because is impossible to visualise more than three variables in graphs, three variables are chosen as input variables and three as output variables. The following variables are chosen for the output:

- Sailing speed;
- Number of ships;
- Average box handling time.

The other variables are systematically varied. This results in a lot of data, which has to be analysed. As an example **Figure 1** shows the ship's speed as a function of the number of ships and the handling time.

21.4.1 Selection of feasible round-trip scenarios

The exploration model has produced 11880 data points in the solution space. The solution space must be narrowed down to just those options that do meet the qualifications. This requires criteria for rejecting or adopting certain solutions. These criteria can be:

- Commercial demands;
- Local conditions;
- Technical limitations.

Commercial demands
Analysis shows that the competitiveness of the system very much depends on its ability to offer short transit times. The vessels have to compete with land

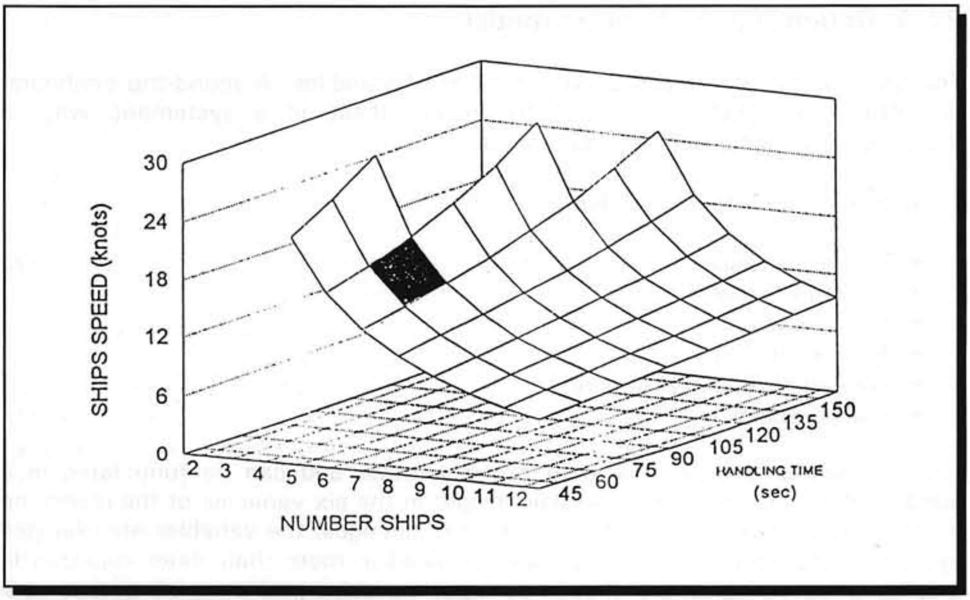


Figure 1: Ship's speed as a function of the number of ships and handling time

transport. A transit time of approximately three days is acceptable, two days is most desirable.
Also imported is the calling frequency of the ships. The ship can call twice a day, once a day or every second day. All options are kept under consideration.

Local conditions
The estimate is that the system can attract about 20 to 30% of the total market of transferable goods. The transport has to be adapted to this figure. All scenarios that require more than 30% are rejected. Scenarios with less than 20% are interesting as an introduction scenario and are not rejected.
The Swedish winters require a minimum ship deadweight. This deadweight is about 3000 tonnes or 250 loaded boxes.

Technical limitations
The most important technical limitations are average handling time and sailing speed. A preliminary estimate of the average handling time indicates a range from 45 till 75 seconds per box. Solutions with sailing speeds in excess of 30 knots are rejected, because of the high energy consumption.

After applying these restrictions, the solution space is narrowed to 225 options. This number is still too high. In order to get a more refined picture, all remaining options were put into a database, The options are ranked according to the following criteria:

- Calling interval;
- Average handling time;
- Box capacity of the ships;
- Transit time;
- Number of ports;
- Transport costs.

Calling interval
A two day schedule has several disadvantages, therefore all these solutions are rejected.

Average handling time
During the progress of both the round-trip analysis and the concept selection process it became clear that the average handling time per box should not exceed 60 seconds. An average of less than 45 seconds can be achieved when not too many boxes are handled in each port. Therefore, the solutions with more than 45 seconds per box are eliminated.

The total number of solutions is reduced to 42 options. These options can be evaluated economically later. The economic evaluation is not meant as a last step in the process of rejecting options in order to isolate one remaining optimum. The economic evaluation describes the cost structure and cost development of each round-trip configuration and provides insight in the effects of changes in the number of ports and ship sizes.

The following two sections describe two ship designs that can be used for the system.

21.5 Conveyor/elevator loader

This ship, which is designed according to the concept of a conveyor/elevator, is a four deck carrier especially suited for the handling of non-stackable cargo units based on the ISO 20 ft. standard on lower corner castings. This means that it is able to carry all types of flats, containers or swapbodies following the ISO, DIN or CEN standard. **Figure 2** and **Figure 3** show the ship's general arrangement.
The cargo handling is controlled by a computer, based on board. The manual operation should be limited to a general survey of the operation. An extensive control desk is situated on the bridge, containing all control functions needed for the survey and whatever actions are needed. The crew is minimised to only four men. All are highly qualified and experienced seamen and technicians.

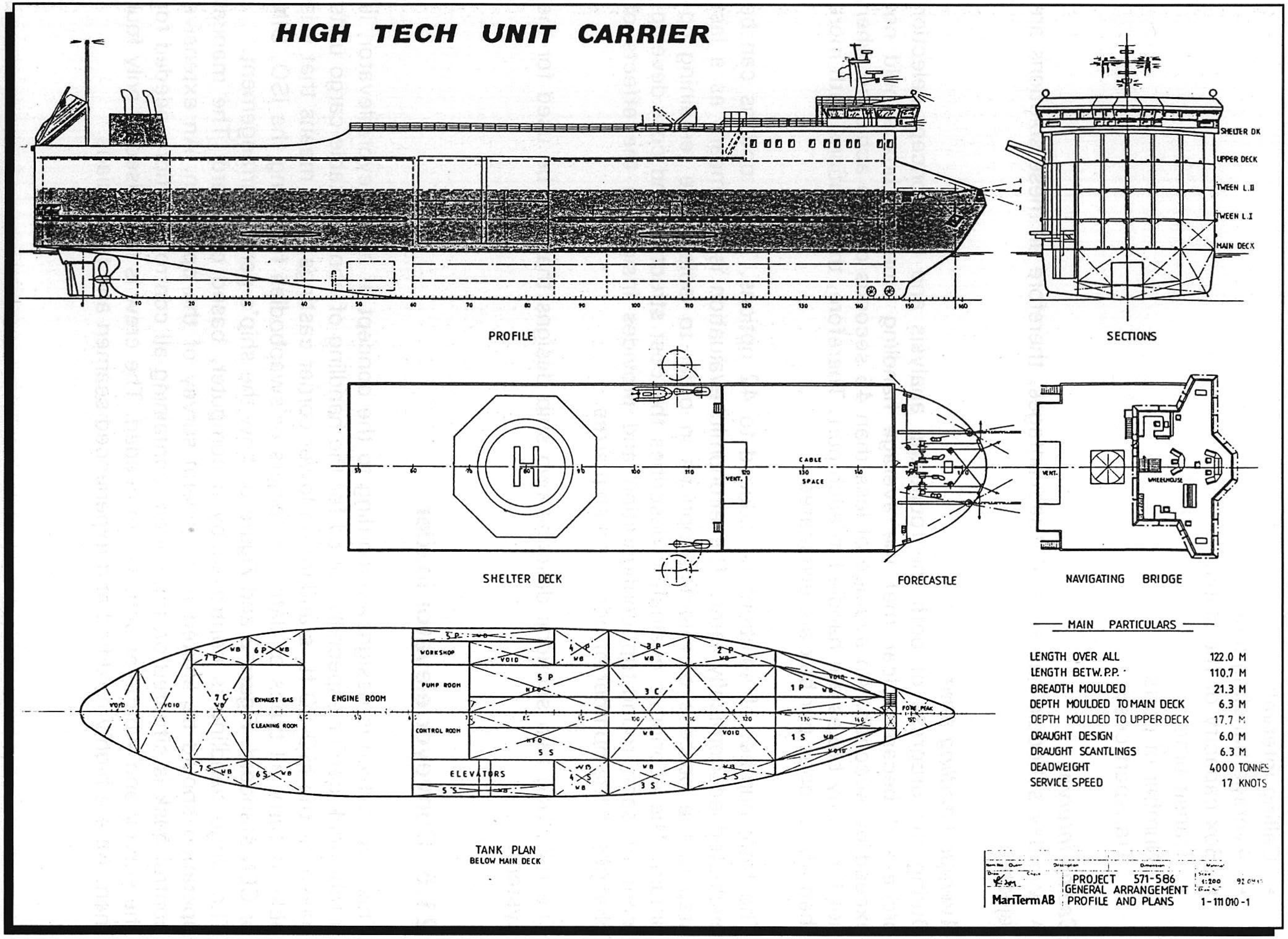


Figure 2: General arrangement conveyor/elevator loader (1)

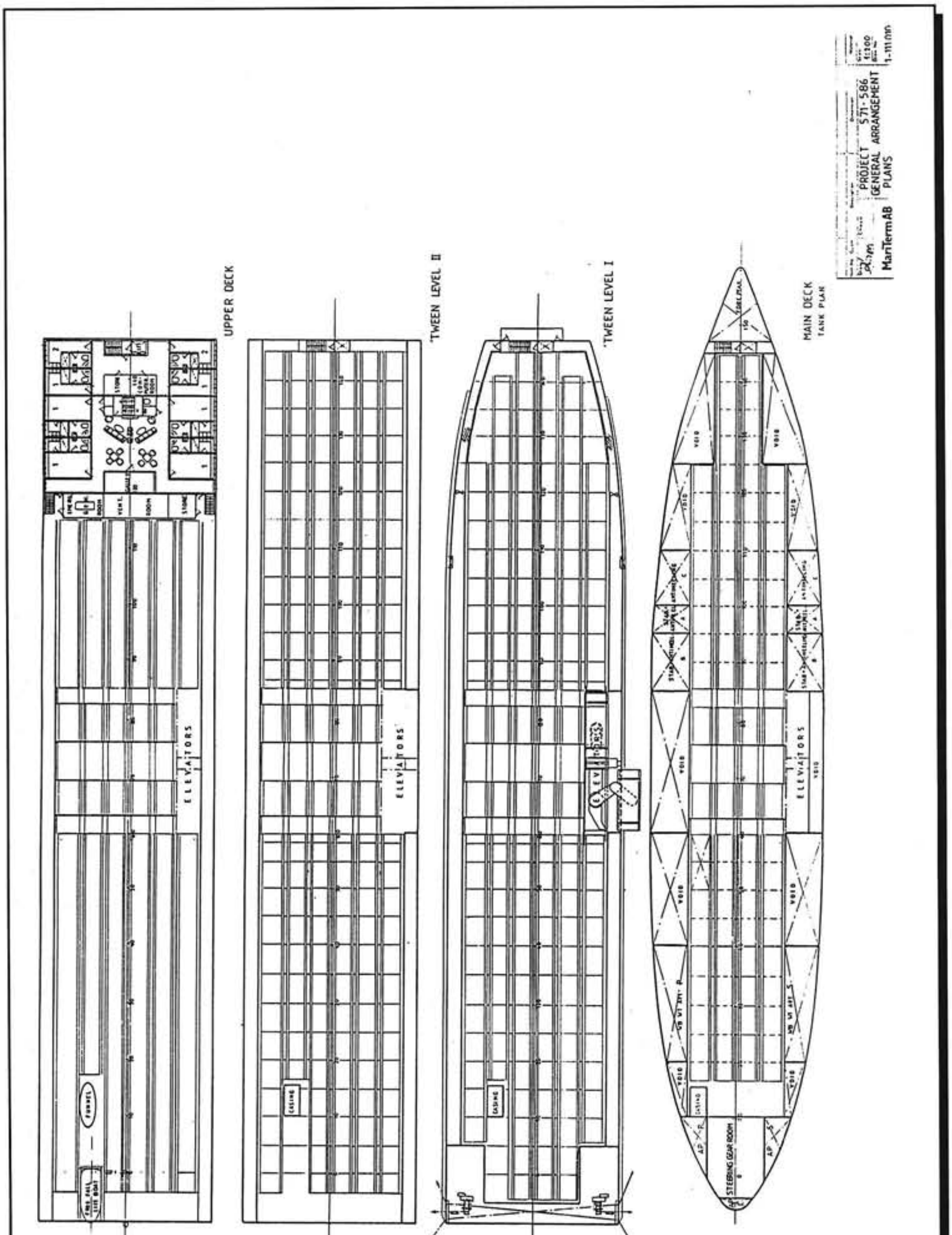


Figure 3: General arrangement conveyor/elevator loader (2)

Cargo handling in the terminals

The ship loads and discharges the cargo units fully mechanically and automatically. The main feature of the handling system is a system that handles non-stackable cargo units horizontally in the ship. For this reason the ship is equipped with a conveyor that can move the units longitudinally in the ship.
The system also comprises a terminal system that allows the units to be handled on and off road vehicles. The terminal system will be the interface between road transport and ship. It must be suitable for intermediate storage of units waiting for the ship's arrival, or being discharged by the ship waiting to be transported to the final destination.

The lorry driver has to inform the system of the character of the unit. The driver will discharge the unit in the terminal, give the terminal the information requested and activate the system. The function of the terminal system is to receive and queue up the units awaiting ship's arrival. A unit entered into the terminal, is individually moved to queue up close to the preceding unit. There will be only one sorting of units in the terminal; northbound or southbound.

In principle the trolley conveyor system consists of a carrier, a rope, a tensioning device and a rotating device. The system features the possibility of moving single units long distances while using very few mechanical components. This means that the device can move units all over a ship's length or the length of the terminal feeding track. The device can also pick out the individual unit and queue it up in a lane. When the unit is positioned it will stay on the friction of the supporting surface.

To allow for the operation between ship and quay facilities the ship must be kept in position within certain tolerance. An integrated fendering and mooring system was developed, capable of keeping the ship within the acceptable tolerance.

Moving the units between the terminal and the ship's deck requires a facility that integrates the handling system on board each ship's deck with the terminal. An air cushion system was designed, which lifts up the cargo and moves it by means of gear wheels acting on a rack on the air suspended platform.

The TCS unit positions the cargo unit on the lift platform. The platform is a part of the side loading lift system arranged on the ship. A docking position will be arranged at the end of the lane where the platform can be docked and guided into a fixed position. The platform will be kept into position so that it will stay fixed independent of the ship's movement at quay side.

The TCS conveyor has tracks running out on the platform and the platform will then be loaded by using the TCS to position the unit on the platform. Then the platform will be retracted and transferred by the lift to the proper deck where it docks. The transfer of the unit from the platform to the deck must be made by a device that does not interfere with the TCS running longitudinally on ship's deck. The transfer can be made by an air suspended platform which goes under the unit and lifts it to move it to the proper position transversely on the ship's deck.

Units to be positioned in the ship will be transferred to the proper transverse position by the assistance of the air cushion platform until it is in position to be picked up by a longitudinally running TCS unit. This unit runs in the full longitudinal length of the ship's hold and will move the unit to its final position in the vessel. Once the units are put down in position they will rest on the supporting steel bars.

Feasibility of the concept

The feasibility calculations are based on a system consisting of seven ships trading the east coast of Sweden. The number of port calls is 14. In the sea transport system it is considered that there is one terminal with the capacity of the full size of vessel (400 units in turnover), one terminal of an average turnover capacity of 200 units, three terminals with an average capacity of 100 units per call, four with a capacity of 50 units and five with 50 units in average capacity. The stay in the ports is based on the full capacity turnover in each terminal which will be maximum four hours.

Running costs

Maintenance and technical service on board the ships are intended to be performed by shore-based personnel according to a planned maintenance system. Some minor maintenance and repairs must be carried out by the crew. Maintenance carried out on board should be minimised. The total crew on board is to be composed of four persons, two masters and two for technical support. Two crews are needed for each ship.

The average situation for the shore personnel is to carry out their work at port calls. As the port calls are to be very short, it is some times necessary for them to follow the ship on a sea voyage. This will evidently lead to higher working costs due to overtime compensation and travel expenses.

Capital costs

To obtain a correct price for the ships, three shipyards have been asked to deliver an offer regarding the cost for newbuildings. The prices differ between 155 MSEK (dec 1992) for the construction of each ship to a price of approximately 240 MSEK.

Cost for the handling equipment in the ship
The project has included a complete design of the handling system on board the ship and in the terminal. The total cost of the handling equipment inside the vessel has been calculated to 13.5 MSEK for the sideport equipment installed in the vessel and 10 MSEK for the total handling equipment inside the vessel.

Cost evaluation of automatic handling in the terminal
For manual handling it will always be the net cost for the number of units handled, which is to be calculated. In the automatic operation the capacity in the terminal has been calculated to be 150% of the average handled number of units. In principle the cost for an automatic handling system is fixed in time. The running cost for the terminal will be very small. The fixed cost consists of the interest and depreciation of the investment. Ordinary manning cost is running cost that follows the general cost increase.

Distribution cost
The total cost includes the cost for transporting the cargo all the way from door to door. In a domestic shipping service we have considered the average distance to the sea terminal to be 50 km. The cost of a multipurpose vehicle suitable for the transport of units is given by one of the trucking companies participating in the study. The tariff for the specific type of vehicle 375 SEK/h and the normal calculated speed for a vehicle in distribution traffic is 20 km/h. If half of the transports are considered as return transports the total transported distance will be 1.5 x 30 km = 45 km. The total time consumed will then be 45 km/20 km/hr = 2.25 hrs. The cost for each handled unit will in this case be 2.25 hrs x 375 SEK/h = 845 SEK, or if the average cargo weight is set to 12 tonnes the cost per ton equals abt 70 SEK.

Total costs
The calculation is also based on a utilisation of 60 % of the system. The calculation is based on a 7 days per week service. This will give a two way cargo capacity of about 2,475,000 tons annually. We have estimated this to be the volume of domestic cargo shipped between the Baltic sea districts in Sweden. Still we know that the major volumes of cargo are made up by the cargoes shipped between Sweden and the continent.

A cost analysis should also include the transport service from the sea terminal to the shipper/consignee in domestic transports. According to above this will give a cost of 2 x 70 SEK/tonne. The total amount will be added to FIO 111 + Terminal 29 + Port 5 + Land transport 140 SEK/tonne totally 285 SEK/ton nefrom door to door for a transport of 1 000 km based on 60% utilisation of the shipping system. This corresponds to a total cost of ***0.28 SEK/tonkm***. This cost is within the region of what a bulk transport by rail will sum up to if the railway could perform a door-to-door transport.

21.6 Train unitloader ship-terminal system

The ship

The second design is the train unitloader. The cross section of this ship is shown in **Figure 4** and the general arrangement in **Figure 5**. The cargo capacity of this ship is 390 swapbodies (C-715) in the cargo hold and 90 on the two train loaders. The ship is also suited for 460 TEU in the hold and 108 TEU on the two train loaders.

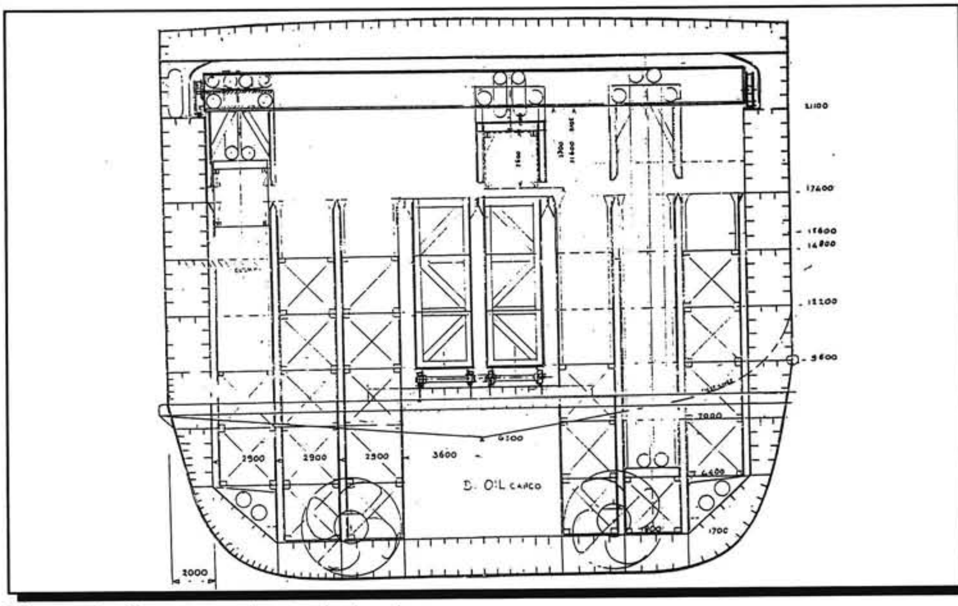


Figure 4: Cross section train loader

There is an empty space under the train loader deck. This space can be used as a payload tank (3740 m^3). This combination ro-ro/tanker is not new. Ro-ro/tank ships are already used in Scandinavia. They transport forest products southbound and bulk cargo northbound.

The ship has a length of 158 m. and a breadth of 28.8 m. The deadweight is 12,700 tonne. To provide maximum floatability in the aft, during a ro-ro procedure, the aft has the same shape as a heavy lift vessel of Mammoet Shipping.

The ship is equipped with a twin screw propulsion system and two bow thrusters. This feature is essential for the manoeuvrability in the ports and a fast

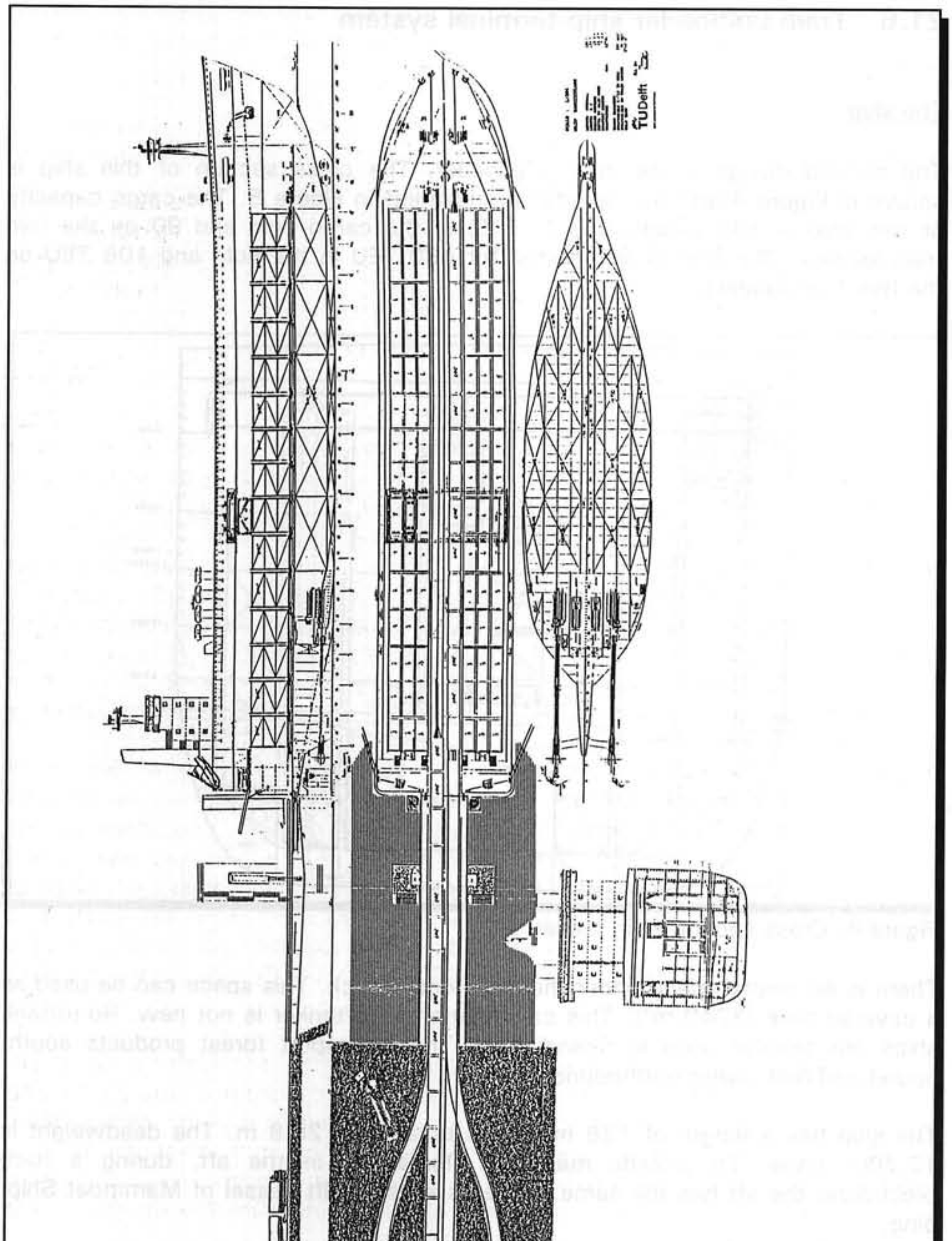


Figure 5: General arrangement train loader

turnaround time at each terminal. The accommodations are placed in the aft, because of the noise during sailing in ice. It also provides a better view on the terminal's linkspan.

To get an impression of the stability in different load conditions, three extreme cases have been examined. Calculations show that the maximum change of the height of the aft during a ro-ro operation with two train loaders simultaneously (0.5 m for one train) is one metre. When the trim angle is 0°, before the ro-ro operation starts, the maximum trim angle during the ro-ro procedure is 1° (0.6° for one train). The maximum static heel angle during the ro-ro procedure (loading one train and the second train on the terminal) is 1.5°.

The terminal design

The terminal consists of four rail lanes with a gantry crane that is capable of loading and unloading the units from the platform cars of the train loaders onto a truck. **Figure 6** illustrates the layout of the terminal.

Each rail lane is equipped with a propulsion system to move the platform-cars on the terminal. The propulsion system consists of a small buffer truck, which is fixed to an endless steel rope. During a ro-ro operation, the terminal's buffer truck is connected by a rigid connection to the first platform-car that comes out of the ship and pulls the whole train loader further onto the terminal. A similar propulsion system is already used to park railway wagons without using a locomotive.

Per port call a maximum of 90 units are unloaded and 90 units loaded, using two train loaders. A daily call, means that there is one ship visiting per terminal per day. This concept is designed in such a way that the operations on the terminal are independent from the ship's operations. That means that in one shift, for example from 9.00 to 17.00, eight train loaders must be loaded or unloaded. This brings the capacity of the gantry to 90 * 2 = 180 units in 8 hours or 22.5 units/hour. This is far under the maximum gross capacity of a terminal gantry, which is approximately 40 units/hour. So one gantry terminal crane is enough for unit handling.

During unit handling on open sea, the movements of the unit, when it hangs under the crane, have to be minimised. The propulsion system of the gantry and trolley must be designed in such a way that the automatisation of the crane moves is possible. To determine the workability of the under deck gantry, it is necessary to analyse the ship's motions in a wave spectrum. The maximum permitted motions and accelerations of the crane determine the maximum sea state in which the under deck gantry is operational.

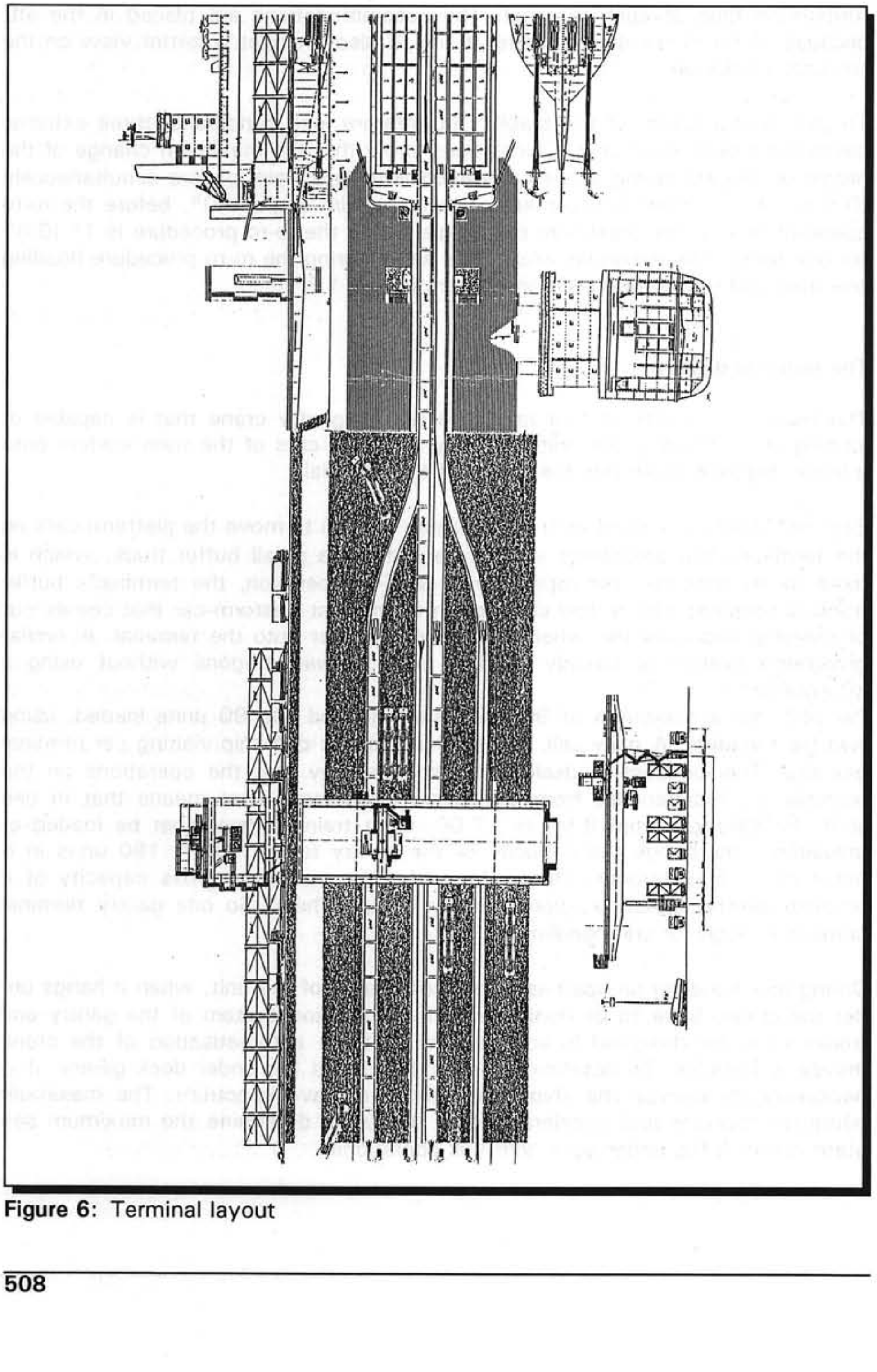


Figure 6: Terminal layout

The natural pitch frequency of the ship gets in resonance with seastate 6. At this seastate the wave energy remains negligible and the damping of the ship in the spectrum induces small on board accelerations. The natural roll frequency is in resonance with seastate 8-9. The wave energy at these large seastates induces high roll accelerations and motions, especially in beam seas.

If the workability of the under deck gantry is restricted to a:

- Maximum roll angle: 9°;
- Maximum linear acceleration along the gantry track: 4 $m.s^{-2}$;

Then the handling of units on open sea can be done up to seastate 7.5 on the Beaufort scale.

Feasibility

Ship costs

The costs distribution of the train unitloader concept is different from a conventional feeder service. The Required Freight Rate (RFR) of a conventional feeder service does not include handling costs on the terminal (stevedores). The RFR of the train unitloader ship-terminal system is a ***RFR on quay to quay basis*** (including terminal handling charges).
Voyage costs, running costs, capital costs, etc. have to be calculated independently. The total exploitation costs per year of the system were calculated, as well as the performance per year of the system. The first divided by the second leads to a Required Freight Rate on a quay to quay basis.

One average round trip is defined. This average round trip will be used to calculate all the costs and the performance of the system:

- Round trip distance: 1600 n.miles;
- Round trip sailing time: 6 days;
- Distance between ports of call: 100 n.miles;
- Loading/unloading time per port: 1 hour;
- Manoeuvering time per port: 1 hour;

Exploitation costs per ship
The diesel oil consumption is about 2.3 tonnes per port call. Per year one ship visits 60 round-trips, 17 ports each, is 1020 ports. This results in a fuel consumption of 2350 tonne/year. The fuel costs are NLG 1,818,506.-/year

Port charges
The port charges are estimated as a function of Length * Breadth * draught. For the shortsea trade the port charges of a feeder are approximately NLG 1,- per L*B*T per day. This is without the cost reduction of the pilot costs and port charges due to the frequency of the calls.

Per year one ship is 45 days in ports (60 round trips, 18 hours port time per round trip). For an average draught of 6.8 m the port charges per year are NLG 1,392,420.-/year

Capital costs
The price of one train unitloader, including all technical arrangements such as two under deck gantries, stern door, train-loader and its propulsion system etc., is estimated at NLG 65 million. For the entire system the annuities are calculated with a depreciation time of 20 years and an interest rate of 7%. The capital costs are NLG 5.7 million/year.

Operating costs
The train unitloader is a ship with a high degree of technology, which increases the capital costs to a level which is higher than normal, but comparatively low crew costs. In general, ships exclusively equipped for automation and low demand for maintenance, high tech ships will need smaller crew. For cargo handling, the train unitloader needs 4 crew members extra. The crew costs are calculated in accordance with Dutch rules. In total, there will be 14 crew members on board. The total operating costs are NLG 2.7 million per year

Total exploitation costs for one ship per year
The cost for one ship in a system consisting of six ships is NLG 11.7 million/year.

Terminal costs

The terminal costs are calculated for a dedicated terminal, this means without the stevedoring costs. The newbuilding price of one terminal includes every technical arrangement for the cargo handling. The handling is carried out by one shift per day from 9.00 to 17.00. With one man on the gantry, one man on the ground and two men for the reception and security, the total of four employees per terminal is sufficient.

Capital costs
The newbuilding price of the terminal including civil engineering, linkspan, terminal gantry, train-loaders and their propulsion system, etc. is estimated on NLG 15.5 million per terminal. With a depreciation period of 20 years and an interest rate of 7%, the costs per terminal are NLG 1.37 million/year.

Operating costs
These costs include man-hour costs, repair and maintenance costs. The manning costs and the maintenance costs are estimated on NLG 0.5 million respectively NLG 0.2 million per year for one terminal. This is a total of NLG 0.7 million/year.

Total exploitation costs for one terminal per year
The total costs per year NLG 2.1 million/year per terminal

Total exploitation costs of the system

The exploitation costs for one ship are NLG 11.7 million/year and the exploitation costs for one terminal NLG 2.1 million/year. The total exploitation costs of a system consisting of 6 ships and 9 terminals are NLG 88.8 million/year.

The total investment for six ships and nine terminals is NLG 531 million. This brings the annuity with a depreciation period of 20 years and an interest rate of 7% at NLG 46.75 million.

Performance

The performance of the system is defined as *Swapbody.mile/year* and in *TEU.mile/year*. The performance of one ship with an average utilisation ratio of the cargo hold of 50% is: $23*10^6$ swapbody.mile/year or $27.2*10^6$ TEU.mile/year. The performance of the system is: $6 * 23*10^6 = 138$ swapbody.mile/year or $6 * 27.2 = 163.2*10^6$ TEU.mile/year

During one round trip one ship visits 16 ports. For 60 round trips per year and six ships in the system, the total ports call for the system is 16 * 60 * 6 = 5760 ports/year. 100% utilisation of a train-loader corresponds with 90 swapbodies or 108 TEU. Assuming that the average utilisation ratio of a loaded train loader is 50%, the number of swapbodies entering (and leaving) the system is 0,5 * 90 * 5760 = 259,200 swapbodies/year or 0.5 * 108 * 5760 = 322,560 TEU/year.

By dividing the total number of transported units per year with the total exploitation costs of the system per year, we obtain a Required Freight Rate (RFR) in NLG/unit.mile on a quay to quay basis. The RFR for a swapbody C-715 differs from the RFR of a 20 ft. container. We assume that the ratio between these two RFRs is the same as the ratio of maximum C-715 and TEU capacity. The maximum capacity for one ship is 480 C-715 or 568 TEU.

$$\frac{Swapbody\ C\text{-}715_{max}}{TEU_{max}} = \frac{480}{568}$$

$$= 0.845 = \frac{RFR_{TEU}}{TEU_{C\text{-}715}}$$

The RFR for a 20 ft. container transported 500 miles on a quay to quay basis with an average utilisation ratio of the ship's cargo hold of 50% will be NLG 275,-. The transit time for such a distance (with four port calls will be 1 day and 17 hours.

CHAPTER 22: DECISION SUPPORT SYSTEM FOR THE PLANNING OF CHEMICAL TANKERS

22.1 Introduction

In the transport of liquid bulk by tankers, the shipping of chemicals is the most complex type. This complexity is generated by the high technical standards required for the transport, the strict international laws and the enormous amount of different grades and types of chemicals.

In the eighties the rising complexity of the management of chemical tankers has mainly been solved by an increase of employees in the management of the tankers. Although the major shipping companies have invested in advanced shipping systems, the operational matters stayed outside the automated systems. Shipping systems are mostly used for accounting, invoicing and market analyses by the management.

This chapter is a study on the possibility of automating the stowage planning, in order to increase flexibility for the commercial department and to reduce time spent on calculations for the stowage planning.

22.2 The organisation of stowage planning

There are three main departments within a chemical tanker company. The technical department, the operational department and the commercial department.

Information transfer

The commercial department will seek for cargo-parcels to be transported. Depending on the parcels available, an initial voyage route is set out. The lay-time and voyage time are calculated from distance tables and port time analyses. This section of the planning is now relatively simplified by shipping systems with automated voyage calculations.

Another part of the voyage planning is the stowing of the products in the vessel. As there are regulations on each product concerning heating, reactivity and coating compatibility, there are restrictions on product/tank combinations and restrictions on binary combinations of products in adjacent tanks. All the information for each separate product is listed in different sources, which have to be consulted before the stowage planning can be executed. The requirements are listed in the following books:

- IMO Rules, BCH/IBC code;
- Marpol rules, Annex I/II;
- USCG rules, 46 CFT PART 140-155;
- ICS tanker safety guide for chemical tanker;
- Chemical dictionaries and handbooks.

As the regulations on stowing are complex and quality and safety are very important, the stowage planning is carried out by the operational department. Authorisation costs time and flexibility so that the commercial department is not able to respond to market demands and changes quickly. Especially when the ship is almost fully booked, adding an extra cargo to the voyage can make the stowage planning a difficult and time consuming job. However, the extra cargo might add up significantly to the profitability.

Giving the commercial department more authorisation in the stowage planning, will result in quicker and more flexible decision making. But planning requires a good knowledge on the regulations and demands of each separate product. This can be realised by keeping up a database with the main regulations on each product. This database is updated each time changes or new products occur. On this, correct, information the operations department can make their stowage plan.

Implementing an automated stowage system

Moving the responsibility of the stowage planning to the commercial department will increase flexibility but at the same time will also increase the job portfolio of this department. This problem can be solved by automating the stowage planning. As the stowage planning is a simple procedure, when all the right information is available, it can be done very fast and accurate by an automated system.

The system has two main functions, which are:

- It is a Decision Support System (DSS) for the commercial department. It must be capable of implementing an offered cargo. It must show the extra revenue made by implementing this cargo and take account of the stability, reactivity, heating and future cargoes;
- When the voyage is (nearly) fully booked the system must be capable of producing the most profitable stowage of the products, concerning revenues, the stability, reactivity, heating and future cargoes.

There are lots of aspects that determine the performance of a stowage. Performance indicators can be divided into two groups. The first group is directly related to the revenue of the ship at this voyage and future voyages. The second is related to operational matters. These are:

- Performance indicator concerning revenues:
  1. The total revenue per day on the voyage;
  2. Number of tanks still open for extra cargo;
  3. Tonnage still available in empty tanks for extra cargo.

- Performance indicators relating to handling matters:
  1. Trim and needs for ballasting;
  2. Cleaning requirements.

If such a program will be used by the commercial department, it is clear that there will be a reduction of calculation time for stowage planning. Also it might be possible to find some empty tank space for a cargo that calculations by hand would not have found.

22.3 Problem definition

Parameters

A ***vessel*** has a number of tanks, which each have the following parameters.

- Tank coating, either stainless steel, zinc coating or epoxy coating;
- Volume;
- IMO type, either 1, 2 or 3;
- Position in the vessel, longitudinal and transverse:
- Adjacent tanks;
- Maximum SPG to be loaded in tank.

There is a number of cargo parcels that must be stowed in the vessel. The cargo parcels have different kind of parameters. The cargo parcels are all listed in the ***voyage list***, per *parcel* is defined:

- Product;
- Minimum quantity;
- Maximum quantity;
- SPG;
- Minimum ship type, 1, 2 or 3;
- Coating compatibility;
- Heating instructions;

- USCG group;
- Cargoes that are not allowed to be stored in adjacent tanks;
- Loading port;
- Discharging port.

The cargoes have to be stowed in the vessel in such a way that no cargo parcels are stowed in Non Compatible (NC) cargo tank combinations and no NC binary cargo combinations are stowed in adjacent tanks. Because of the minimum and maximum quantities of the cargoes there can be a variation of the quantity that is carried on a voyage. Therefore the revenues of a trip can differ.

22.4 Information flow/AF diagrams

As described in the previous section, the information needed for stowage planning is very complex. In this section the information flows and activities that are needed during the planning, are described according to the Structured Analyses Design Technique (SADT).

In **Figure 1, Figure 3** the stowage planning is presented by the block. Input of the planning comes from the left side, output goes to the right side. The control of the system is represented by the arrows on the top.

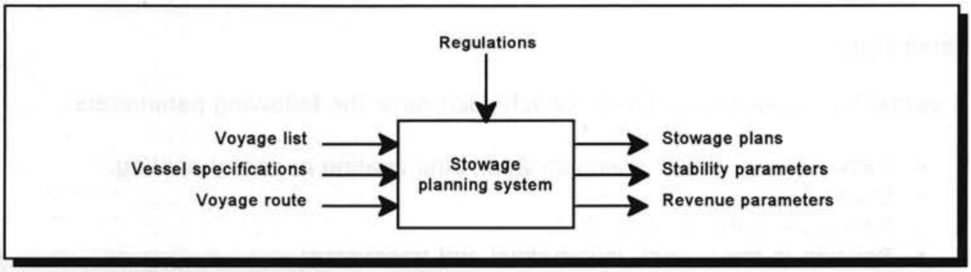


Figure 1: Activity factor diagram of the stowage planning

The *stowage planning* consists of four parts. The determination of the Non Compatibilities, the sorting/stowing, the stability calculations and the performance calculations. In the next sections these activities.

Determining the NCs
From the heating range and the maximum adjacent temperature of the products, the cargo combinations that are not allowed to be stowed in adjacent tanks are determined. The two parameters, temperature and maximum adjacent temperature are found in the product specifications.

The cargoes that are not allowed to be stowed in adjacent tanks, because of reactivity, are determined by of their USCG group number. The USCG compatibility chart, and the exemptions are used for this purpose.

The NC cargo tank combinations are determined by the product specifications (coating compatibility and the minimum IMO ship type required) and the tank specifications (IMO ship type and coating).

Sorting/stowing of the cargoes
When all NCs are determined, the stowing of the products in the tanks can be carried out.

Stability calculations
When the stowage has been made, the stability is calculated. The stability must comply with minimum requirements.

Performance calculations
When the stability is verified the performance is determined. Performance in-decator are: Revenue, volume of the empty tanks and coating of the empty tanks.

The acitivity factor diagram of this process is shown in **Figure 2**, the activity factor diagram for determining Non Compatibilities is shown in **Figure 3**.

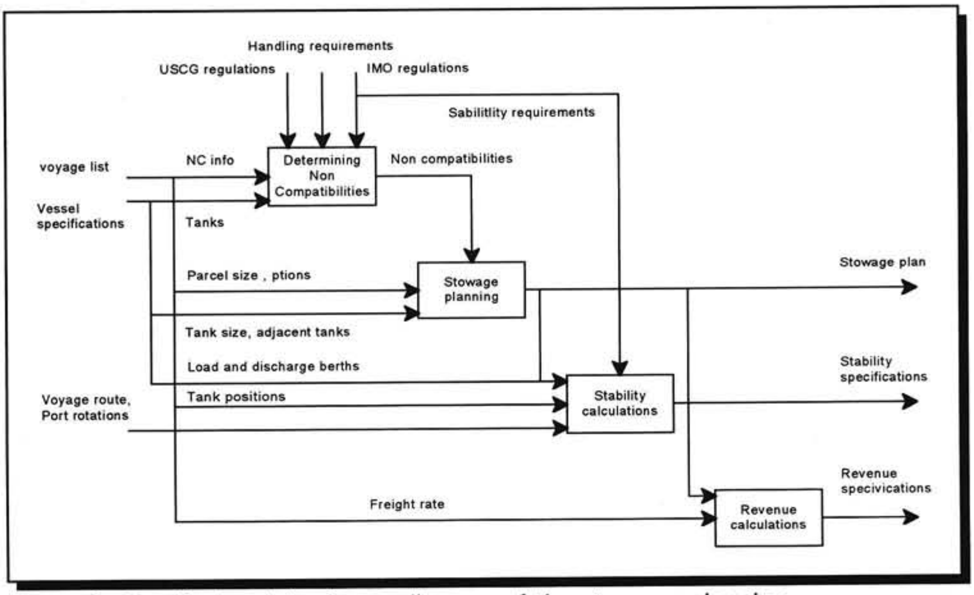


Figure 2: Detailed activity factor diagram of the stowage planning

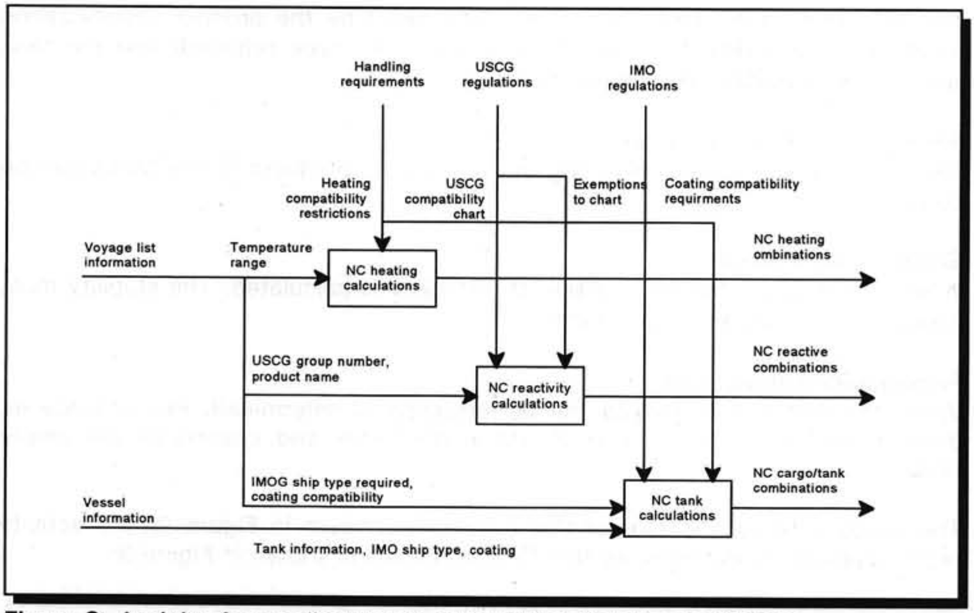


Figure 3: Activity factor diagram of determining Non Compatibilities

22.5 Heuristic programming

It is difficult to define an optimal stowage plan. An optimal stowage plan should have high revenues, low costs and flexibility in the rotation through the port.
Because of the many variables, a complete enumeration will cost too much calculation time, therefore, the Best Selection Algorithm was developed. In the particular problem of stowing P products in T tanks there can be a maximum of T^P stowage plans. To prevent the system from being to slow for practical use a special algorithm has been developed. The algorithm will only select the best three possible solutions per cargo. Compared with the full enumeration this is a big reduction of the number of calculations.

Figure 4 shows the enumeration tree. From every node three branches start. The branches end in a node. The nodes represent a stowage plan that is partially filled. Every branch is a cargo that is put into a stowage plan. The cargoes are stowed in the best three possible ways.

The algorithm builds the tree starting in the fist node, which is an empty stowage plan. From each node the three branches are build. The algorithm will first go to the node of the best tank. This means that the system will directly go to stowage plan 1. When all cargoes are stowed or when there are no possibilities to stow the next cargo, no branches are found. The algorithm will go back one step and cut off the branch. In this node it will look for other

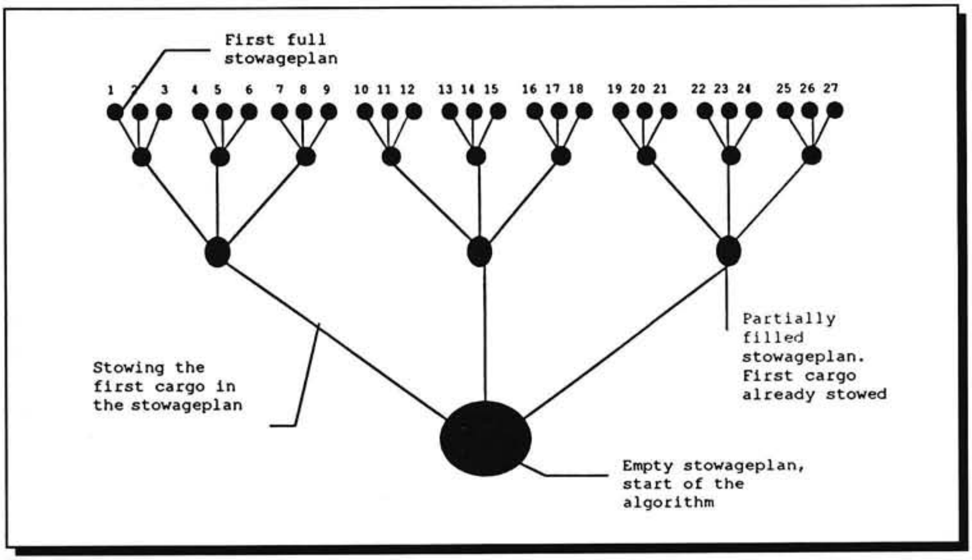


Figure 4: The enumeration tree

branches. Because of this procedure the algorithm will finally end in the first node and will stop.

The calculation time in each point depends mostly on the possible combinations of tanks that have to be calculated to find the three best tank combinations. The maximum amount of calculations for a cargo find all the possible tank combinations is:

$$\frac{n!}{(n-r)!r!}$$

Where:

n = Number of possible tanks

r = Tank needed to stow this cargo, r depends on the size of the parcel

To keep calculation time low, it is best to stow the products with few compatible tanks and many Non Compatible other cargoes first. This recudes the number of combinations, for it prevents that at the end there is no space left for these cargoes.

It is also best to stow big parcels first as these require a combination of tanks. Therefore, they will require more calculation time. When one puts these parcels at the start of a stowage planning, it saves calculations. To find a good sequence for the cargoes a formula is used for the performance. The formula is:
Where:

$$\frac{volume}{X} + h*Y + r*Z - c$$

h = Number of heating NCs
r = Number of reactive NCs
c = Number of compatible tanks

When all binary product combinations are made and between these combinations a heating is checked. This is done by comparing the maximum adjacent heating and the minimum heating of the products. When the maximum adjacent heating equals or is smaller than the other cargoes minimum temperature there is an NC between the products. When all product binary combinations are and the USCG group number combinations are made, for each binary combination the compatibility is determined out of the USCG compatibility chart, presented in a matrix in the program.

In the previous formula the values X = 250, Y = 3, Z = 3 are entered. Now the cargoes are put in order of declining result of this formula. This will be the sequence in which the cargoes are going to be stowed. For each cargo that is going to be stowed the following procedure is carried out:

- All the partially filled stowage plans in which the cargo has to be placed is analysed for NCs. This is done by first comparing the compatible tank array of the cargo with the thanks that are already filled. The tanks that are not already filled, are checked for the contents of the adjacent tanks. If there is an NC cargo in an adjacent tank, the cargo cannot be placed in this tank.

- Out of the possible tanks, the combinations of tanks, or only one tank, are made, which can contain the minimum volume of the cargo. The slack of this combination will be calculated. The slack is the volume still empty in a filled tank.

- The stability is calculated. No cargoes are allowed to be stowed on one side of the vessel, exemptions for cargoes which are place in one tank.

- The quality of tank/tank combinations is determined by the following rule. The number of tanks in the combinations, the minimum number of tanks is always the best. When there are more combinations with the minimum number of tanks, the quality is determined by the minimum amount of slack.

- The partially filled stowage plan is copied three times and the cargo is placed in the stowages according to the best three possible tank/tank combinations. Now the next cargo in line is activated to be stowed in the three stowage plans.

- When all cargoes are allocated, the performance of the stowage is calculated. The performance is the revenue of a stowage and the stability much comply with minimum requirements.

Figure 5 shows an output screen of the DSS program.

22.6 Information and data supply

For the stowage planning in chemical shipping accurate, information is required. There are three main types of information. First, information about the freight. This information is usually put down in the booking notes and CPs. Second, the product properties and the regulations for the different products are needed. Third, the layout of the ship and its attributes are required. This information is discussed in this section.

CP information

When cargo parcels are offered, during the negotiations, all the conditions for the transportation are set. The main conditions are listed on the booking note and in the Charter Party. Information in the booking note includes loading/discharge port and berths, quantity in MTS, freight rate, options, lay time, demurrage, etc. For the stowage planning the following information is required:

- Product name (unique);
- CP quantity;
- Variation;
- Freight rate;
- Charterer;
- Loading berth/port;
- Port/berth of discharge.

Product information

Product information includes all properties and handling requirements. For the stowage planning, the following properties are needed:

- SPG;
- USCG group number;
- Handling information;

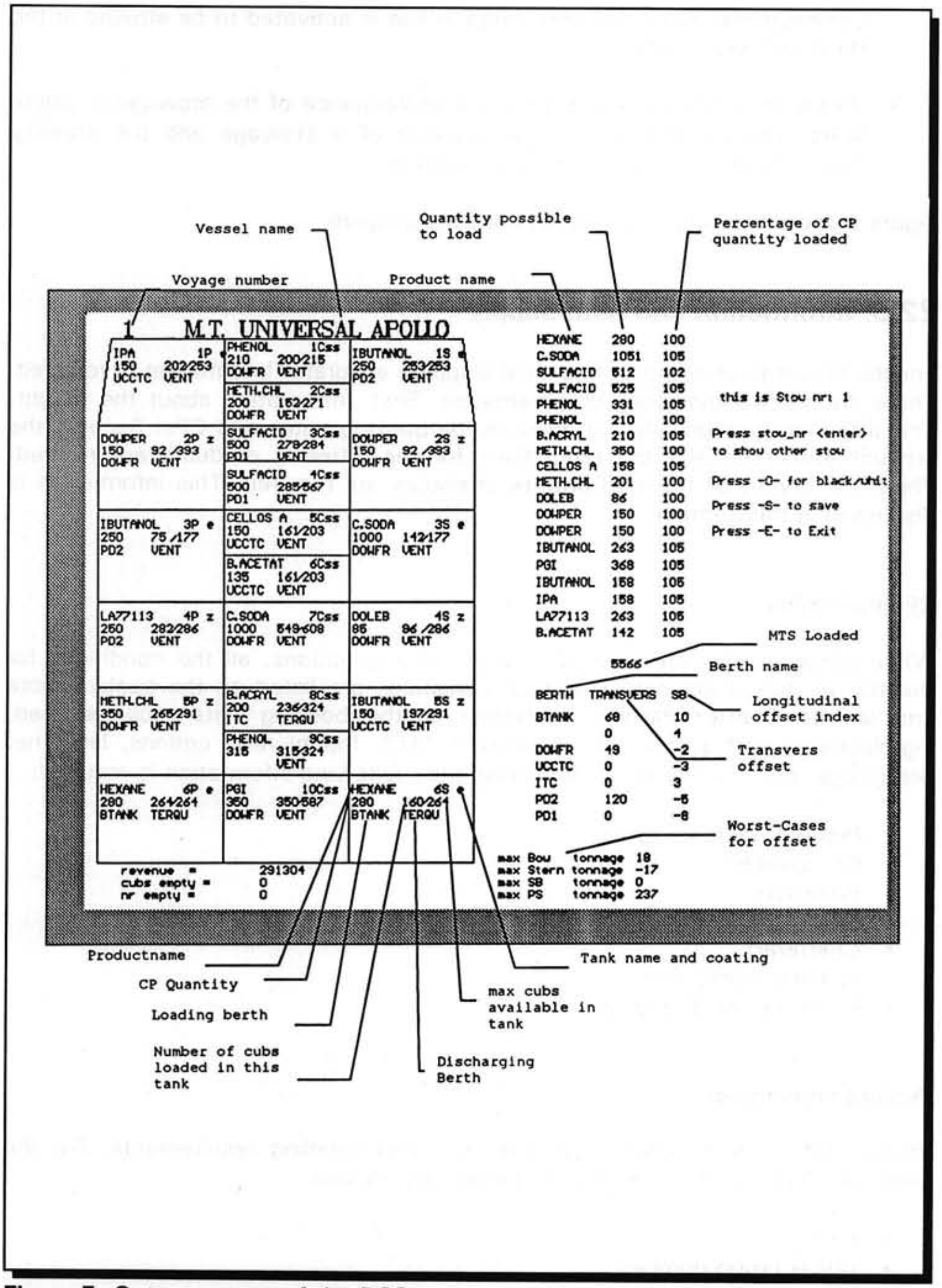


Figure 5: Output screen of the DSS program

- Coating compatibility;
- IMO ship type required;
- Temperature range;
- Maximum adjacent temperature;
- Cleaning conditions.

Vessel information

Vessel information consists of technical information, regulation information, stability information and cleaning information. Per tank is required:

- Technical information:
  - Maximum SPG;
  - Coating.
- Regulation information:
  - Ship type;
  - Adjacent tanks.
- Stability information:
  - Position within the vessel;
- Cleaning information:
  - Condition of the tank.

Databases for the stowage DSS

Voyage list database

The voyage list database holds all information on the cargo parcels. The list contains all product and CP information needed by the stowage system. The fields are:

1. Cargo number = key of voyage list;
2. Product name = product code;
3. CP quantity booked, in MTS;
4. Minimum variation of the cargo, short-loading allowed;
5. Maximum variation of the cargo parcel, extra loading allowed;
6. Freight rate in US$/tonne;
7. Charter name;
8. Loading berth;
9. Discharging berth;
10. Minimum temperature of the cargo (celcius);
11. Maximum temperature of the cargo (celcius);
12. Maximum temperature allowed in adjacent tanks (celcius);
13. Condition of the tank required;

14. Condition of tank after discharging;
15. USCG group number;
16. Specific gravity of the cargo;
17. IMO ship type required;
18. Epoxy coating compatibility;
19. Zinc coating compatibility;
20. Stainless steel coating compatibility.

Product specifications database

The product specifications database contains the information on the products. The fields are:

1. Product code = key to database;
2. Full name;
3. Product group;
4. Product code;
5. Unknown;
6. Specific gravity;
7. U.N. Number;
8. Marpol strategy;
9. Unknown;
10. IMO class;
11. IMO ship type required;
12. coating compatibility;
13. Chris code;
14. USCG group;
15. FOSFA/NIOP;
16. Minimum temperature during voyage;
17. Maximum temperature during voyage;
18. Temperature unit;
19. Maximum adjacent temperature during voyage;
20. Temperature unit.

Vessel database

The vessel database covers all the information on the tanks in the vessel. The fields are:

1. Tank number = key to the tanks;
2. Volume of the vessel in cubic meters;
3. Epoxy coating;
4. Zinc coating;
5. Stainless steel;
6. IMO ship type;

7. Maximum SPG this tank is designed for;
8. Number of adjacent tanks;
9. Adjacent tank number;
10. Adjacent tank number;
11. Adjacent tank number;
12. Adjacent tank number;
13. Adjacent tank number;
14. Adjacent tank number;
15. Longitudinal index;
16. Transverse index;
17. X-position on the screen, for graphical representation
18. Y-position on the screen, for graphical representation
19. Tank name.

22.7 Conclusions

The algorithm works well for the ship type and cargo quantities under study. The calculation time is short enough for the user in the commercial department. The ships have 20 to 22 tanks on board. The number of cargoes is 10-20. The results give accurate information and the stability is sufficient.

The system works well, but only when the right product specifications are entered. Without the right information the system does not work.

Because the product database does not cover all different grades of products, the specifications that are in the database are not accurate enough for the system. Therefore, the interface contains the possibility to change the cargo specifications for each cargo parcel.

CHAPTER 23: THINKING, CREATIVITY AND INNOVATION

23.1 On Archimes and other great thinkers

Arthur Koestler in *"The Act of Creation"* tells the story of the discovery by Archimedes of the principle that gave him world fame. Hiero, the tyrant of Syracuse and protector of Archimedes, had been given a beautiful crown, allegedly of pure gold, but he suspected that it was adulterated with silver. He asked Archimedes' opinion. Archimedes knew, of course, the specific weight of gold - that is to say, its weight per volume unit. If he could measure the volume of the crown, he would know immediately whether it was pure gold or not; but how on earth is one to determine the volume of a complicated ornament with all its filigree work? Ah, if only he could melt it down and measure the liquid gold by the pint, or hammer it into a brick of honest rectangular shape, or .. and so on.

One day, while getting into his bath, Archimedes watched absentmindedly the familiar sight of the water-level rising from one smudge on the basin to the next as a result of the immersion of his body, and it occurred to him in a flash that the volume of water displaced was equal to the volume of the immersed parts of his own body - which therefore could simply be measured by the pint. He had melted his body down, as it were, without harming it, and he could do the same with the crown.

To become immortal as a scientist, like Archimedes, seems to be rather trivial process: take a bath and all will be well. Or even less-tiring is the story of Newton, who sat under an apple tree and saw apples falling to the ground. Instead of defining it as falling, he had the insight - so the story goes - that the apple does not fall, but is attracted to the earth's surface by gravity. He had singlehandedly discovered one of the most important concepts in modern physics. Newton's biography, which will be touched upon later on, does not confirm this fable. But it is stimulating and encouraging to think that by simply relaxing in bath or under a tree, fundamental breakthroughs in science can take place.

Koestler quotes Newton as having said that *"If I have been able to see farther than others, it was because I stood on the shoulders of giants."* One of these giants was Johannes Kepler (1471-1530) whose three laws of planetary motion provided the foundation on which the Newtonian universe was built. They were the first natural laws in the modern sense; precise, verifiable statement expressed in mathematical terms; at the same time, they represent the first attempt at a synthesis of astronomy and physics which, during two thousand years, had developed on separate lines.

Kepler

Kepler did not start his career as an astronomer, but as a student of theology; he was attracted by Copernicus idea of a sun-centered universe for physical or rather metaphysical reasons. He liked the analogy between the stationary objects, namely the sun, the fixed stars, and the space between them, with God the Father, the Son, and the Holy Ghost.

By looking at the sky, Kepler hit upon a question that nobody had asked before: "*Why do planets closer to sun move faster than those that are far away? What is the mathematical relation between a planet's distance from the sun and the length of its year?*" These questions could only occur to someone who believed that the motion of the planet was governed by a physical force emanating from the sun. It was this conviction that enabled him to formulate his laws.

Physics became the auxiliary matrix that secured his escape from the blocked situation into which astronomy had manoeuvred itself. The blockage was due to the fact that Tycho de Braha had improved instruments and methods of stargazing, and produced observational data of a hitherto unequaled abundance and precision. And the new data did not fit into the traditional schemes. Kepler, who served his apprenticeship under Tycho, was given the task of working out the orbit of Mars. He spent six years on the task and covered nine thousand folio-sheets with calculations in his small handwriting without getting anywhere. When at last he believed he had succeeded he found to his dismay that certain observed positions of Mars differed from those that his theory demanded by magnitudes up to eight minutes arc. Eight minutes arc is approximately one-quarter of the apparent diameter of the moon.

Kepler was convinced that the problem of the orbit of Mars was insoluble so long as he felt bound by the traditional rules of sky-geometry. Implied in those rules was the dogma of uniform motion in perfect circles. Finally he concluded simply that the planet's path is not a circle but a curve called an oval. The problem of the planetary orbits had been bogged down in its purely geometrical frame of reference, and when Kepler realised that he could not unstuck it, he tore it out of that frame and removed it into the field of physics. In the words of Kuhn, there was a paradigm shift in science.

Although in the previous examples of Archimedes and Newton it seemed to have cost little effort to come up with new science principles, the case of Kepler shows the reverse. Many years of hard labour of data crunching brought him that the current concept of planetary movements was wrong. His scientific method was one of induction, and he was a Baconian 'avant la lettre', in spite of the fact that his paradigm for looking at astronomy was more or less determined by his theological background about the Holy Trinity and the absoluteness of his religious world view.

Isaac Newton

This remarkable Englishman who lived from 1642-1727, eighty extremely creative years in various professions, ranging from academic to Master of the Mint. He studied and published about such diverse subjects as monetary policy, astronomy, physics, chemistry, mechanics and mathematics. A biography from A. Rupert Hall, titled *"Isaac Newton, Adventurer in Thought"* gives a breathtaking overview of the immense intellectual and sophisticated work of the genius.
His most remarkable, or better, most well-known work was on the differential calculus, or in Newton's language, the calculus of fluxions in the period 1664-1667, 22 years old, at 'The prime of my age for invention'. It would lead too far to elaborate on the many inventions in science that Newton produced during his long live. His biography is a must for all those trained in engineering skills, as understanding the history and background of Newton, creates a better insight in the principles most of us had to learn in the early stages of our studies.
Brilliance in science came to Newton naturally, but also through hard and tireless work. He is the prototype of the creative scientific mind, of which one every century is born.

Other great men

In the Netherlands, one of the best scientific thinkers has been Christiaan Huygens, who was born around the same time as Newton in 1629. His vivid biography by C.D. Andriesse, *"Titan kan niet slapen"*, tells the story of a man who made in many domains of science, important contributions. The biography illustrates again the process of creativity.
One other unique creative talent was of course Albert Einstein. There are many books written about his work and live. One of of his statements about the process of creative thinking which lead him to the great new theories in physics, was that he always saw new theories as visual images. Like in the case of the relativity theory, he saw gigantic men moving in space, which lead him to the definition of relativity; the perception depends on the point of view of the observer. Again changing perception of the reality is the greatest quality of thinkers. His personal life, as described by A. Pais in *"Einstein Lived Here"*, shows the development from Einstein's scientific life into a public figure.
Thomas Edison provides another example of a scientist turned into an entrepreneur. In the biography by N. Baldwin, *"Edison, Inventing the Future"*, the human aspect of his life is told, and that picture is bleaker than the image by the general public based on the scientific breakthroughs he invented. Edison started the phenomena of the industrial firm with an important R&D department.
In the book *"Reinventing the Future, conversations with the world's leading scientists"* by T.A. Bass, lesser gods are interviewed about their theories and the thinking process behind it. In physics, the book *"Genius, The life and science of Richard Feynman"* by J. Gleick tells a fascinating story about the process of science theory in nuclear physics.

In contrast with the physics or mathematics oriented scientists, are the management scientist as Ansoff, Chandler, Taylor, Peters, Sloan, or Porter. Although one should take their efforts very seriously, an amusing view and at the same time overview of these theories is provided by C. Kennedy in *"Guide to the Management Gurus"*. The 33 management thinkers illustrate that during the last six decades the management theory paradigm has constantly shifted; a process that is not likely to end, as by the way in all sciences.

In transportation, there are not so many scientist working on inventions, but a lot of managers, business men work on innovations. J.N. Diebold in his book *"The Innovators, The discoveries, inventions, and breakthroughs of our time,"* tells the story of F. Smith's overnight delivery concept (Federal Express founder), and how he innovated the parcel distribution market.
This less highbrow, in comparison with physics, story of innovation is briefly discussed here, because it shows the type of thinking that is required to innovate in shipping as well.

Innovation in transport: the story of overnight distribution

Frederick W. Smith started on June 1, 1971 the company Federal Express, which was the beginning of a whole new transport segment: parcel services with overnight delivery. Fedex had grown into a US$6 billion company by 1993, and several others have joined the success of Fedex, such as UPS and DHL.
J. Diebold in *"The Innovators"* tracks Smith's origins and success factors. According to Smith, an innovator, or entrepreneurs have some sort of inner-directed zealotry that comes from some psychological impetus of one sort or another; innovators just have this view of something and, in their minds, it is extraordinarily important and it just has to be done. Smith offers some advice which may perpetuate success in a company based on the continuous process of innovation.

The first step in trying to perpetuate innovation in an organisation is to develop a common set of goals or a common philosophy so that everybody understands what you are trying to do. That way there should be a lot of mental concentration focused on just a few things.

The second thing we do in trying to foster innovation is to reward it to the extent that we can through monetary awards and recognition. But far more important than rewarding it, we do not kill people for failing. In other words, it is okay to try something and if it does not work - the fact that you tried is what is important. Of course, if you have got a repeating record of failures - we do not like that much. But we do not chastise or blame people if things do not work. I just cannot tell you how important we feel that is. You have got to allow people the opportunity to fail.

Then the last of the three elements so important to corporate innovation is the need to constantly expose people to new ideas. You have got to get people proficient in the latest thinking in their technical disciplines. You have got to bring in folks who are creative to stimulate their thinking - creating an educational atmosphere, if you will, that keep people on the leading edge of where you are trying to go.

23.2 S-curves of great individuals

Marchetti has analysed the creative production of well-known individuals, such as Botticelli (1445-1510), Shakespeare (1564-1616), Bach (1685-1750), and Mozart (1756-1791) with the help of logistic analysis. The results are shown in **Figure 1** to **Figure 4**.

Botticelli was at the crest of his creative work at the age of 39, while he lived to be 65 years. Shakespeare reached his highest output at the age of 37, while he only became 51 years. Bach reached the 'old' age of 65, and was most productive at 40. Mozart, as we know died very young (35), and reached his highest productivity at the age of 24. This leads Marchetti to the observation that apparently when Mozart died at 35, he had already said and written what he had to do.

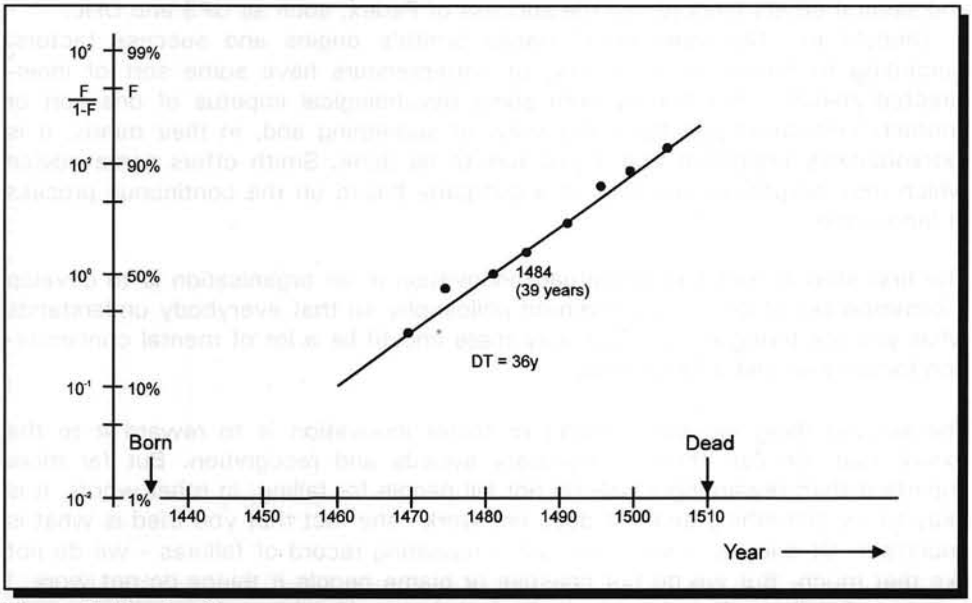


Figure 1: Botticelli

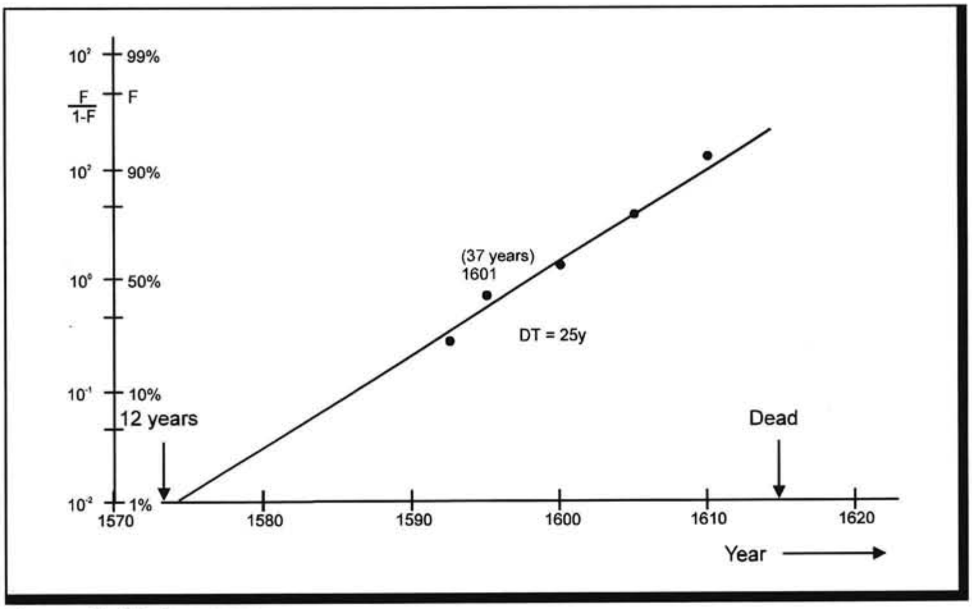


Figure 2: Shakespeare

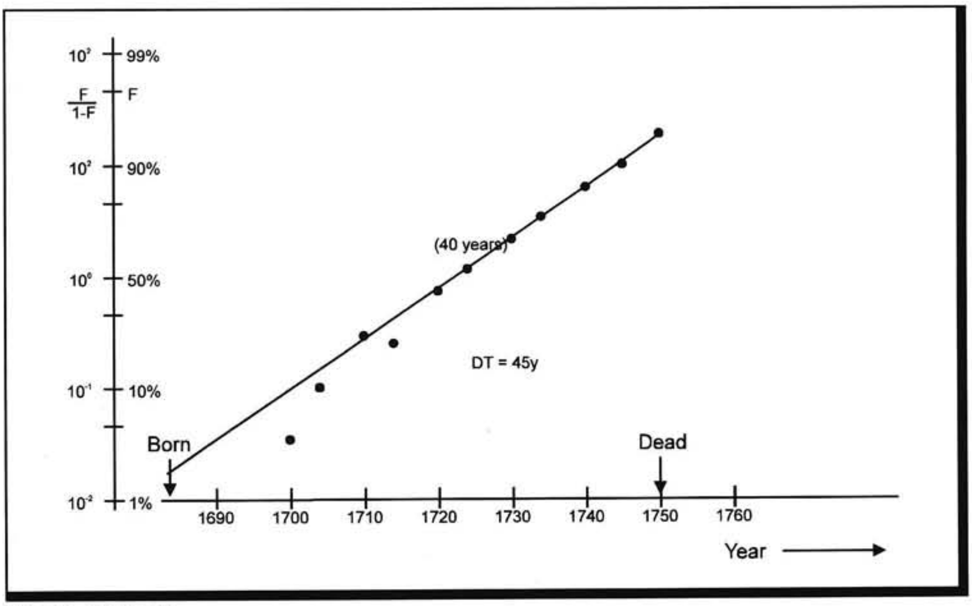


Figure 3: Bach

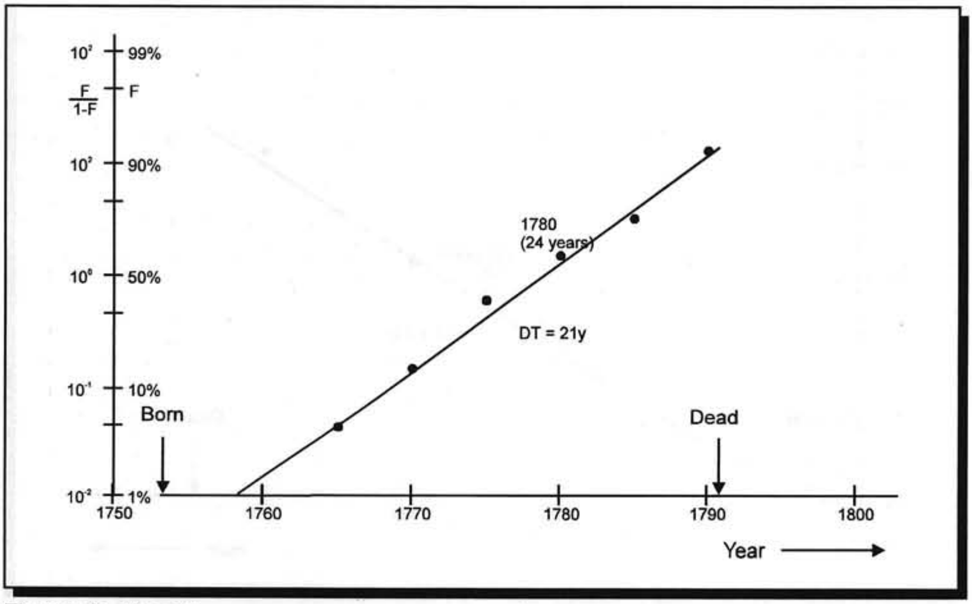


Figure 4: Mozart

23.3 What is creativity: Origins and perspectives

After having discussed briefly some great thinkers, it is time to turn to the basic qualities behind their thinking, which is often called creativity. What makes people creative is the big question.

I.A. Taylor in *"Perspectives in Creativity"* states that definitions of creativity are often misleading. Early definitions of creativity tended to be unitary in nature and they frequently indicated sources or origins of creativity. Some of these origins include:

- Vitalism, in which creativity has a esthetic or mystical source;
- Nativism, or the belief that the origins are rooted in genetics;
- Empiricism, the view that creativity is essentially learned;
- Emergentism, the view that creativity emerges as a synthesis of hereditary and environmental forces;
- Cognition, creativity resulting from thought process;
- Serendipity, the notion that creative discoveries are accidental although the person may be prepared for a sudden insight;
- Romanticism, the belief that creativity originates through unanalysible inspirations and that examining the illusory roots of creativity will destroy it;
- Physiology, the contention that creativity is rooted in the biology of the human organism;

- Culture, or the determination of creativity by the historic Zeitgeist;
- Interpersonal relations, or creativity resulting from or being triggered by group interaction as in brainstorming or synectics;
- Personality, or the contention that the sources of creativity are understandable by examining the development of personality either psychoanalytically or through self actualisation theory.

Taylor proposes a theory of creativity based on the actualisation theory. This theory involves five essential interacting and interfacing components, which includes the person, the problem, the process, the product, and the climate (**Figure 5**).

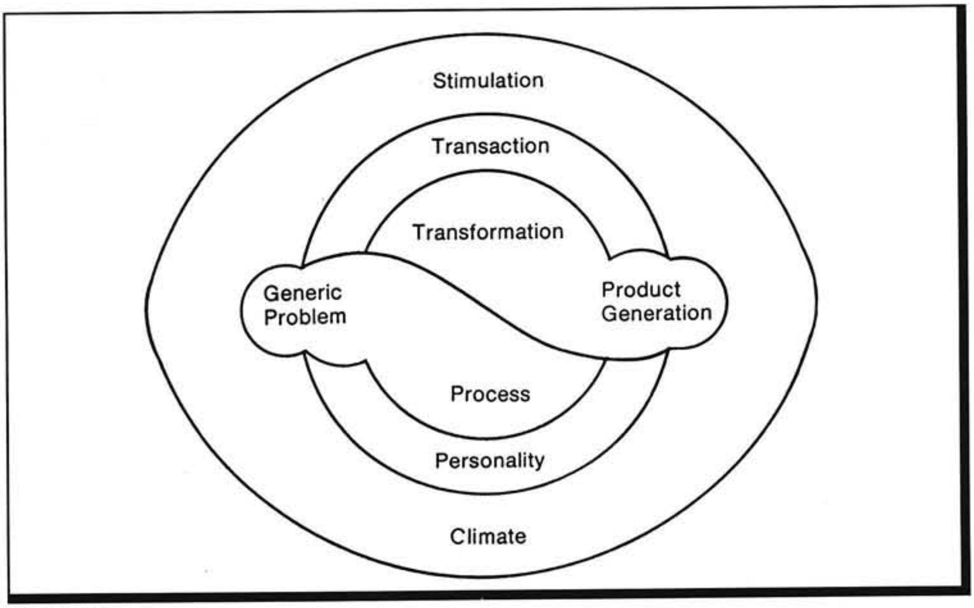


Figure 5

The term 'creativity' is a highly mutiordinal concept, ranging from the spontaneous, expressive drawings of children to the scientific and artistic formulations of Einstein and Picasso. Therefore, conceptually it is necessary to distinguish between different creativity dispositions, levels, states, or life styles. Taylor distinguishes five distinct psycholinguistic clusters of usage of the term 'creativity', each involving different psychological processes. These five are:

- *Expressive creativity* - the spontaneous drawings of children are examples; originality and quality of the product are unimportant.
- *Technical creativity* - is characterised by the proficiency in creating products; the emphasis is on skills. at the expense of expressive spontaneity. Stradivarius is an excellent example of technically creative person.

- *Inventive creativity* - is characterised by the display of ingenuity with materials. Creativity at the inventive level, does not result in new basic ideas but in new uses of old parts and new ways of seeing old things.
- *Innovative creativity* - at this level basic assumptions or principles are understood so that modification through alternate approaches is possible.
- *Emergentive creativity* - the most complex form of creativity is considered to be emergentive creativity, involving the most abstract ideational principles or assumptions underlying a body of art or science. In rare instances, an entirely new principle or assumption, around which new schools flourish.

The great thinkers can be classed in the latter category, in which once in a while paradigm shift in science occur. Most of the creative mortals in the business or university environment are either involved in innovative or inventive creativity. Can an individual improve his creativity and climb the ladder of creative success towards emergentive creativity? The techniques described later on may contribute to this goal. A first step in the direction is to understand the cognitive thinking process as defined by J.P. Guilford in *"Way beyond the IQ"*.

The structure-of-intellect model

Guilford has studied the human mental abilities that contribute to the potential for creative production, and the mental functions that go with them as part of human intelligence. Intelligence is a collection of abilities or functions for processing information. Abilities differ with respect to kinds of information, and to kinds of operations we perform with information.
Items of information differ in two ways: substantive differences, or *content*, and regarding form, or *product*. All items of information are constructed by our brains, and the constructs are products.

The content categories are like codes or languages. The individual products are like words within those languages. There are four major kinds of contents recognised. These are:

- *Figural*: this is generated rather immediately from input from the sense organs as what we call perception. The most important kinds in this category are visual-figural and auditory-figural. It takes different abilities to process these two kinds of information;
- *Semantic*: perceptions lead to thoughts, in particular imageless thoughts;
- *Symbolic*: this is composed of signs or labels that commonly stand for items of other other kinds of information, such as letters, words, numbers, mathematical expressions;
- *Behavioural*: this includes feelings and emotions, such as pleasure, effort, anger and disgust, which are communicated by body language.

Within each of the content areas of information there are six kinds of products or brain-produced constructs. *Units*, which Guilford has named the Structure-of-Intellect (SI) model.

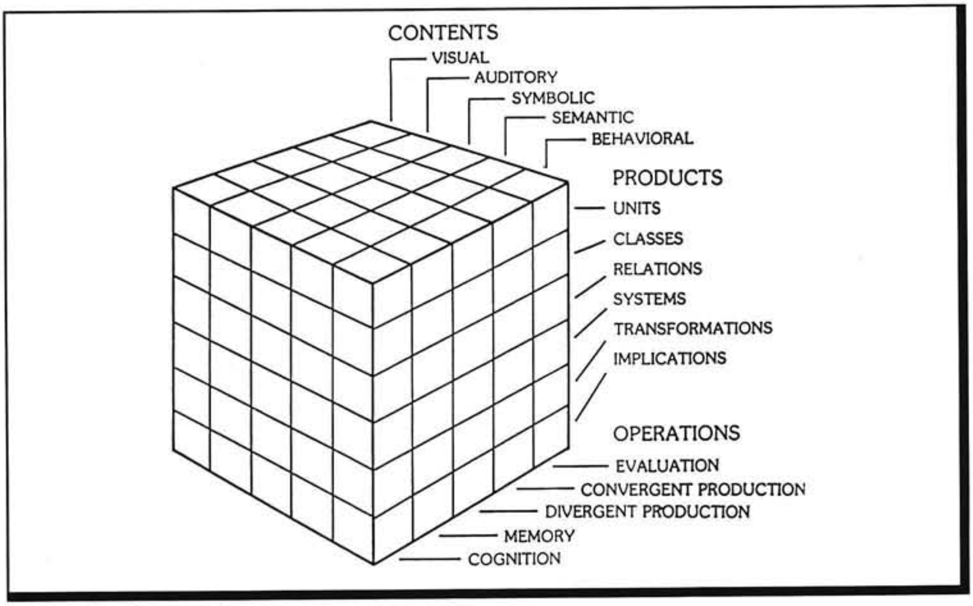


Figure 6: SI-model

Creative problem solving involves a great many different intellectual functions that are represented in the SI model. Thus, creative abilities are a part of intelligence, not something apart from it. Most critically involved, particularly at the stage of generating ideas, are the divergent-production abilities or functions and those involving transformations of information. The former provide an abundance of alternative ideas; the latter a flexibility in the structuring of information so that alterations and adaptations can occur.

Improving creative thinking

Various procedures for improvement of potential for creative thinking have been tried experimentally and the most susccessful methods can be closely related to the theoretical basis of the SI model. The basic concepts behind creativity techniques for problem solving and opportunity search, which will be discussed in the following chapter, are based on the purposeful manipulation of the transformation processes as defined in the SI model. This model provides the overall paradigm for the creativity techniques which attempt to change the day-to-day perception of the reality.
Edward De Bono states in his book *Teaching Thinking*, that the teaching of thinking is *not* the teaching of logic but the *teaching of perception*. Logic is

tangible and direct. We can make rules and observe mistakes. It seems to be the only definte thing that can be taught. In its proper place, logic is a tool of perception. It is perhaps most important in the metaphysical arguments which involve words and concepts. The role of logic is to show what is implicit in the concepts used and to expose contradictions.

Logic is used as a tool to make explicit what is implicit; we use mathematics in order to see clearly what is implicit in a set of relationships.

Perception is the procesing of information for use. Thinking is the processing of information for use. That is why perception and thinking are the same thing.

CHAPTER 24: STIMULATING CREATIVITY IN THE DESIGN PROCESS

Some people believe that creativity is something you are born with and which cannot be learned, or stimulated. This believe depends to a large extent on the defintion of creativity and the domain in which it is required. In this context it is meant as the creative ability which is part of the tools for improving problem solving and opportunity search capabilities of the individual.
Many books have been written on these techniques and many more workshops have been organised to expose and train people within organizations in the art of creativity techniques. In the framework of this book, the general concepts behind these techniques will be discussed and some will be demonstrated briefly. Those readers who have a wider interest should try to attend the various workshops which are frequently offered in most of the countries in the world, or read some of the books listed in the Chapter Notes.

Why are people limited in their creativity, when confronted with a problem or opportunity? The answer is quite simple: they run out of perspectives to look at the issues. They are used to look at the world with a view and perception based on their paradigms, which have been formed over the years through parental guidence, education, work experience, or religious convictions.
The objective of the use of creativity techniques is simply to question the current perception by stimulating purposefully other ways of looking at the problem or opportunity. In short, the techniques, or tricks, *manipulate on purpose the perception of the individual*.

There are four basic ways to classify the perception-manipulation techniques. The two main principles of perception-change triggers are:

- The use of *association/analogy/excursion* techniques;
- The use of *confrontation* techniques.

The two basic work methods which can be applied to the previous two categories are:

- Strengthening the intuition;
- Systematic-analytical approach.

These four approaches to perception change and stimulation of creativity in problem solving and opportunity search, are shown in **Table I** with some examples of the techniques.

Idea genering principle Method	Association/analogy/excursion	Confrontation
Strengthening of intuition	**Methods of strengthening associative intuition** * Brainstorming methods - Classical brainstorming - Discussion 66 - Two level brainstorming - Negative brainstorming * Brainwriting methods - Method 635 - Brainwriting pool - Idea card brainwriting - Gallery method - Idea-Delphi - Collective notebook method	**Methods of intuitive confrontations** * Synectics * Visual confrontation methods - Picture folder brainwriting - Visual confrontation in the group * Semantic intuition
Systematic analytical approach	**Methods of systematic association or anology** * Multi-dimensional morphology - Conceptual morphology - Sequential Morphology - Modifying morphology (attribute listing) * Progressive abstraction - Value analysis	**Methods of systematic confrontation** * Morphological matrix * TILMAG

Table I

Brainstorming

This method belongs to the category of *strengthening the associative intuition*. Brainstorming was the first formal idea-generation technique, developed more than fifty years ago and is by now more or less generally accepted as a useful approach. It works by simply forbidding (deferring) any judgement or evaluation as ideas are being expressed in a small group of people (6-8) under the guidance of a process-facilitator. The effect is to produce a substantial flow of ideas in a short space of time. "*Quantity breeds quality*" is the brainstorming claim, and it is true to a point: the more ideas there are, the greater the chance of one or more of them, or a hybrid made up from its parts of several ideas, providing a solution.

Brainstorming demonstrated decisively the inhibiting effect of judgement on the production of ideas; remove the risk of criticism and the ideas flow.

There is much more to say about this technique, but one remark will suffice. Brainstorming has become such a common word, that every manager claims to 'brainstorm', which is often no more than kicking around a few ideas.

There are useful variations on the brainstorming method, such as negative-brainstorming, idea-Delphi, collective-notebook method, brainstorming with Post-Its stickers on a large billboard, brainwriting, *ideacard-brainwriting*, etc. The latter technique can be particularly useful in large groups. The method is based on a nonverbal, writing technique. Each participant writes one idea on a piece of paper and passes it on to his neighbour, who does the same to his neighbour, etc. Each participant has to associate on the new idea that is written by his neighbour and write it under the previous idea. This way, each participant tries to follow and build upon the previous idea of somebody else.

Force fit

There are also a number of techniques to help you generate ideas that are unusual, original, or high in novelty. These techniques involve forcing yourself to move in new or more unusual directions, or as some put it 'going on excursions'. Force fit is one of these, which is based on trying to associate randomly objects in the room around you to your problem.

Attribute listing

This is an analytical technique for identifying possible areas of improvement in a product. It starts from a factual description of each component of the product in physical terms, describes the functions of each component and then considers whether each attribute of each component might be improved. The systematic procedure ensures that no stone is left unturned in the search for opportunities for improvement. After the initial procedure, ideas can be considered for possible ways of improving the attribute.

Attribute listing can be used as a tool for *value analysis*, by relating the cost of each component to the function it performs. Aspects to the product which are disproportionally costly in relation to the value they provide can be identified, triggering a search for ways to reduce or eliminate the cost and improve the value. Value analysis is the basis for another design methodology called value engineering.

Morphological analysis

Like attribute listing, morphological analysis is a systematic search for opportunities for improvement. It starts with a listing of the parameters of the problem, and then each one is subdivided into as many different form as possible. The subsets are charted in the forms of matrices and all combinations of the features are considered. Quickly the number of combinations becomes very large. They are then screened to identify any which are novel and attractive.

Synectics

Reinforcing intuition through confrontation is achieved by using techniques like synectics, idea-checklists, and the like. These two will be briefly discussed. The synectics process involves two main elements: make the unknown known, and make the known unknown. Especially the latter element, making the known unknown, is a useful way of manipulating the current perception. Synectics uses four approaches to achieve this, all based on analogies: personal analogies, direct analogies, symbolic analogies, and fantastic analogies. The principle underlying the personal analogy is coined with the phrase "*identify yourself with the object, and try to describe what you feel, see, hear, how you move, etc.*" An example of direct analogies is bionics. As this is a very useful tool, it will be discussed separately.

Bionics

There are many ways to look for direct analogies as a source of inspiration; the users of bionics look in nature as natural phenomena carry an almost infinite creative variety of materials, processes, systems, etc. which can easily be copied to another situation. If a fighter plane manufacturer wants to develop a new landing gear for use on an aircraft carrier, he studies in extreme detail the grasshopper: the insect has an unparalleled capacity to absorb energy in its legs. For the development of energy-efficient lighting, they study the firefly which produces by an enzyme-catalysed chemical reaction cold-light with nearly 100% efficiency; the well-known velcro-fastener has been developed on the basis of the clinging burdock burr; the depth control of fish is done by the inflation and deflation of a bladder, a principle which is used in submarines; the bulbous nose of the dolphin helps to lower the resistance in water, a principle which is copied on ships, etc.

Confrontation idea-checklist

Osborn, who laid the foundation for creativity techniques in *Applied Imagination* (1953), proposed a series of idea-spurring questions, which could be very helpful for stimulation new ideas, within an individual's mind or among the members of a group. They can be remembered by the first letters of each trigger-word, which make the word SCAMPER: Substitute, Combine, Adapt, Modify, Put to other uses, Eliminate, Rearrange, Reverse.

There are more systematic-analytical approaches of generation ideas based on confrontation, which are for example a combination of the morphological matrix approach, but used in a 'confrontation' setting.

One technique, which does not fit a specific category, is worth mentioning: *mind mapping*. It is a new note-making technique, which is shown in **Figure 1**.

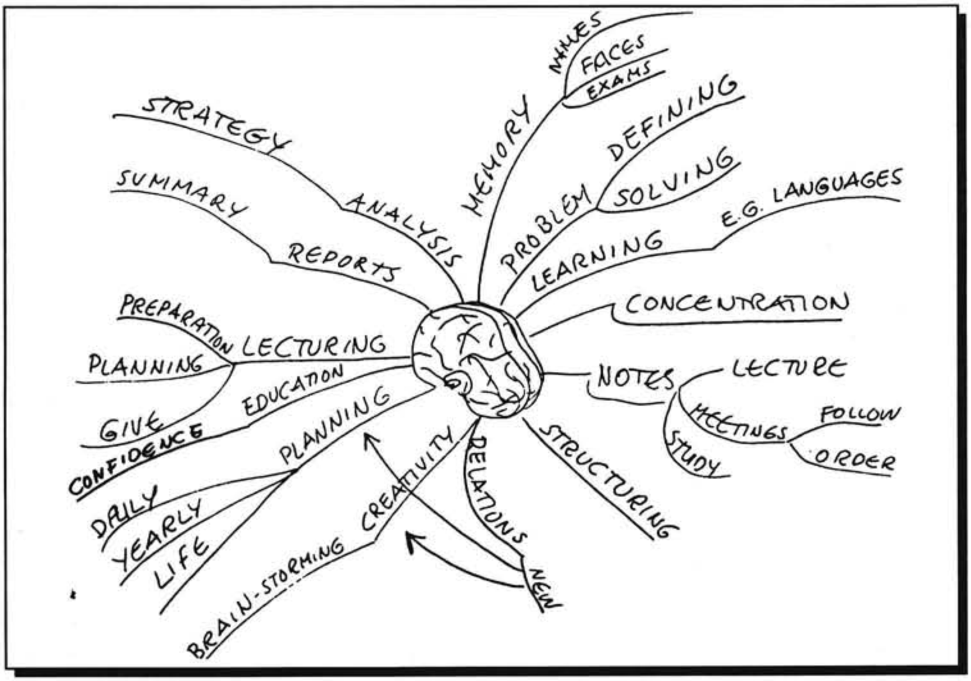


Figure 1: Mind mapping

It can be useful in a number of situations, such as structuring of a problem, generating direction for brainstorming and other idea-generation techniques, and creating different perspectives to look at a problem.

When to use a specific technique?

Gryskiewicz distinguishes four categories of idea-generation, ranging from adaptive to innovative, which is schematically shown in **Figure 2**. These are:

- Direct: ideas generated answer the problem statement directly;
- Supplementary: ideas generated involve a new use, application or build on the traditional ideas;
- Modification: ideas generated involve a structural (or more significant) change from the traditional ideas;
- Tangential: ideas involve entirely different uses or applications than those from other categories, a real shift in perspective.

There are many more aspects that could be discussed, such as the organisation of creative problem solving teams, the selection and evaluation of ideas, the communication, etc. The latter aspect is for example well treated in Nolan's

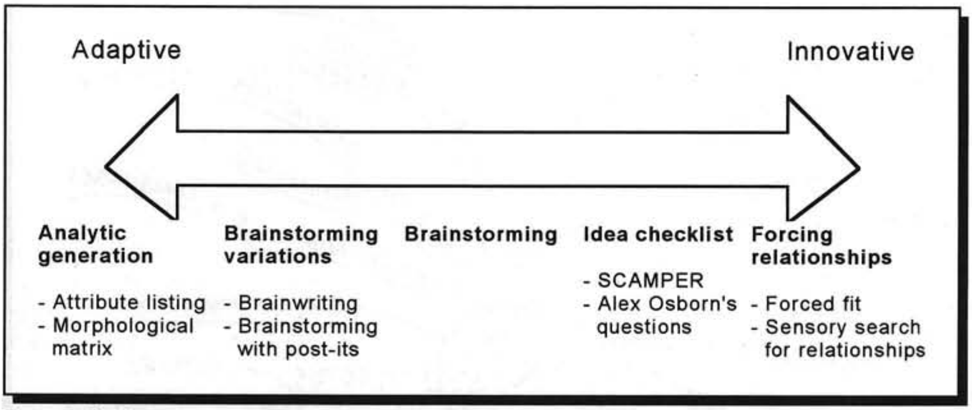


Figure 2: Category of idea generation

"The Innovators Handbook".
The objective of this chapter is simply to demonstrate that many tools are available to help stimulate the creativity in the design process. It is not a guarantee for a better design, nor should it be applied on ill-defined problems. Generating ideas is more fun than defining a problem (or opportunity) and therefore many individuals and teams use the creativity techniques in a too early stage of the creative problem solving process, which then only adds to the confusion. This leads to ineffectiveness, which has given creativity techniques in the academic community a non-serious (scientific) status.
Idea-generation is used in the design innovation process at the end of a long journey during which the problem/opportunity is well defined, and through benchmarking the relative performances is established, as well as the potential for technology improvement through the construction of S-curves.

CHAPTER 25: DESIGN INNOVATION IN SHIPPING METHODOLOGY

Introduction

Design in shipping is a complex matter, but basically no more complex than the design process in other industrial segments. Introducing innovation in the design process may add even more complexity, but as long as these are improvement innovations, the process does not change fundamentally. However, if the designer wishes to strive for basic innovations, which form a clean break from past concepts and designs, the design process loses its comfortable structure. Where to start and how to structure the opportunity search for new shipping concepts? The objective of this book is to provide the designer with a methodology which will help him and his colleagues to successfully accomplish this challenging design job, without 'en route' getting stuck in the solutions of the past.

The Design Innovation in Shipping (DIS) methodology is not a miracle cure which leads automatically to innovations, but rather a road map, a tool box or a set of instructions to help structure the design process. And foremost, to become aware that DIS requires relatively little engineering design, but a whole lot of detailed analysis of markets, logistics, handling, operations, technologies, performance indicators, benchmarking against competition, and the like.

The innovative design will not be created by a freewheeling brainstorm session only, but by arduous work concerning the total ramifications of the ship and its environment. This will provide the triggers for innovation. Environmental analysis in the widest sense forms the springboard for the designer to apply his combination of creativity, engineering skills, intuition and rational evaluation knowledge which will ultimately result in a design innovation.

Design is difficult to learn from textbooks, and this situation is even further complicated by fact that the curriculum of most engineering schools has shifted over the years from engineering *design* to engineering *science*. To the extent that it seems now imperative to create postgraduate designer courses, which will, however, not compensate for the basic lack of engineering design education. The engineer is first of all a person who understands design, and is equipped with the tools to conceptualise, analyse, visualise, synthesise, calculate, innovate, transform and modify the physical reality, either through products, structures or services.

The maritime engineer, which used to be in the past 'naval architect', has evolved into an analytical person with too little architectural qualities left. It is about time to restore this balance, and hopefully this book and its DIS methodology may help achieve just that.

The DIS methodology is based on a *twelve steps process*; these steps define the following issues:

Step 1- Who designs and who innovates?
Step 2 - Organisation, innovation management, concurrent engineering;
Step 3 - Problem definition/opportunity search;
Step 4 - System modelling;
Step 5 - Benchmarking of parameters;
Step 6 - S-curve performance, life cycle, logistic;
Step 7 - Formulation innovation triggers;
Step 8 - Stimulating creativity;
Step 9 - Defining preliminary ship concepts;
Step 10 - Applying traditional maritime design methodologies;
Step 11 - Evaluation criteria and ship concept selection;
Step 12 - Detailed design and feasibility of ship innovations.

The twelve steps will be discussed below in more detail.

Step 1 - Who designs and who innovates?

There are shipyards which develop standard designs for reefers, bulk carriers, product tankers, chemical tankers, container ships, etcetera.
Sometimes these standard designs involve basic innovations, but usually they stay at the level of improvement innovations. The designs are made with the objective to create a series of ships, which will allow the yard to create economies of scale in product development and shipbuilding. Also the designs are optimised from a production perspective, in order to minimise steel weight and/or welding metres. There are of course exceptions such as the Kvaerner Group, which is at the forefront of design innovation in shipping.

The shipyards develop their design based on previous experiences, benchmarking of competitive designs and discussion with owners/operators.
Their objective is however to sell ships, or rather, to minimise idle hours of the workforce and maximise the utilisation of the production facilities.
Design innovation is risky for a shipyard, as it requires an investment in the project team, the research of tank testing and marketing to the prospective owners. Therefore they confine themselves usually to improvement innovations and leave the more basic work to shipowners and specialised consultants.

Another reason why shipyards are reluctant to spend a lot of money on basic ship innovations is the fact that most designs cannot be properly protected by patent rights. Most basic innovations, like the container, are in themselves simple, existing technologies which are used in a new combination. In practice this is very difficult to protect; some countries, like Japan, opt for a policy of patent flooding which means that they have registered thousands of ideas on minor design details. In case somebody comes up with a similar idea, which is

part of a larger new concept, they sue and offer as a way out by cross-licensing, in the best of cases. This is usually at the detailed design level; new ship concepts can not really be patented, although there have been exceptions like the L.A.S.H. (Lighter Aboard SHip) and to some extent the Superflex tanker.
Shipyards which developed innovative designs cannot adequately protect their conceptual design, as it will quickly be copied with minor modifications by others. They therefore concentrate in general on marginal design improvements, which are of course also important when the current design is in the mature phase of the life cycle.

This leaves it to the shipowners and consultants to develop basic innovations, new concepts for existing maritime trades or new trades, which until now could not move either because of the high freight level, or the too costly handling of the product.
The problem with the shipowners in exercising this role is, that since the eighties most of them have shed their staff in an attempt to stay afloat. They often have taken rescue to flags of convenience, ship management companies, and reduced overheads to the minimum, concentrating on finding employ for their ships and fending off the banks that attempted to take possession of the asset.
An owner without an operational/nautical department, without crew management, without maritime engineers or naval architects is hardly able to initiate new designs. Although the chartering department, which acts as an in-house broker, will spot opportunities for improvement.
Luckily, a whole new category of owners also appeared during this through in the freight market on the scene: the industrial shippers/shipowners. For example the large forest products manufacturers, who control the whole logistical chain, and who are able to take a holistic view of shipping.

This new demand and the increasing reduction in captive know how within many shipping organisations, facilitated the work of the independent consultants to some extent. However, the lean years in shipping have made also within this category of designers many casualties.
The bottom line is that there is in general not a lot of expertise left within the shipowning community. If, in spite of this, the shipowners wishes to innovate the design of a ship, he has to rely for a major part of the work on outside help; this means that he has to be prepared to allocate resources (funds) to such a project, and not merely internal human resources which would lower the procedural and psychological threshold for trying to innovate.

So, the first hurdle that should be taken, is to create a budget for the project. It is no use to try to innovate on the basis of inadequate funding. This also forces the shipowners to really make a positive choice for a research (or rather *development*) project. He can also create a consortium, such as in the case on the ECO Tanker from Platou and partners.

The design innovation team, managed by the shipowner, should also contain a combination of different experts, from chartering, logistics, operations, finance, design, cargo handling, equipment suppliers, ship construction and building.

The budget constraints usually puts a limit on the number of man-hours and thus time that can be spent on internal research, but also on, for example, tank testing.
Most of the owners balk at a budget which exceeds US$500,000; this means that innovation in shipping is, unlike in many other industries, more or less a shoestring operation. It has to be fast and low cost, there is little room for mistakes and experimentation.
Many owners find the above amount already way beyond their means and simply believe that detailed design and all kinds of model testing will come free from shipyards, once they have provided them with a basic conceptual design. If they spend US$200,000 on the development of a new concept, than this represents already a major investment. In view of the very large investment in a ship (up to US$100 mln), the R&D budget is in general extremely small.

In sum, basic design innovations should be initiated by the shipowner, as he has the best insight into the multi-faceted triggers for innovation in design, but he has to do this in close cooperation with many other experts.
Innovation budgets are in general very meager and shipowners expect a lot of mileage out their R&D dollars, which demands a lot of creativity in putting together a team of experts, who are willing to work often for nothing but a promise of future involvement in the project, a sort of moral IOU.
Consultants may find it hard to live from just that.

Step 2 - Organisation, innovation management, concurrent engineering

The small R&D budgets for design innovation dictate a very efficient organisation and lean management; the short time-horizon of many shipowners demand a 'quick & dirty' mentality of the project management. In other words do not study too long, there is a small time-window, come up quickly with results otherwise your support will run out. Design innovation in shipping is often characterised by this 'short-termism'.
The most efficient way to achieve the lowcost, quick results is by using the concurrent engineering design concept; the different fields of expertise should work in parallel, and coordinated by the a strong project manager from the shipowner. This should be a senior executive, as he has to translate the owner's ideas into the design, watch the budget, achieve results, and liaise with the rest of the shipping company's management and directors. He needs to have lobby power and respect from his peers. A DIS project should preferably not be managed by a researcher or a manager from another staff department. It is the line manager, with little time available and time to waste who should chair and coordinate the design innovation team. But who can also the defend the

vulnerable project during its gestation period. The DIS should should thus look like indicated in **Figure 1**.

Step 3 - Problem definition/opportunity search

Once the concurrent engineering design team is formed and the budget approved, as well as deadlines set, the first important phase of the design project is to define and redefine the design problem or rather the design opportunity.
This seems a trivial start, as the project got approval on a problem definition or outline specification of the design task. Nevertheless, there are many ways to look at the world, and the perception determines what you so, or want to see.
Consider the story of the two shoe-salesmen who were sent at the start of this century to Africa in order to scan the market potential for their footwear. After six months of surveying the potential, one came back very depressed, as there was no market for footwear in Africa since 'everybody walked barefoot'.
The second salesman returned in euphoria as his potential market seemed to be unlimited as 'everybody walked barefoot'.
A well-known problem: two people looking at the same situation and seeing different things.
More recent examples from the maritime industry show that the question of perception and the definition of the 'real' problem is very difficult: double hull oil tankers and safety measures for passenger ferries.

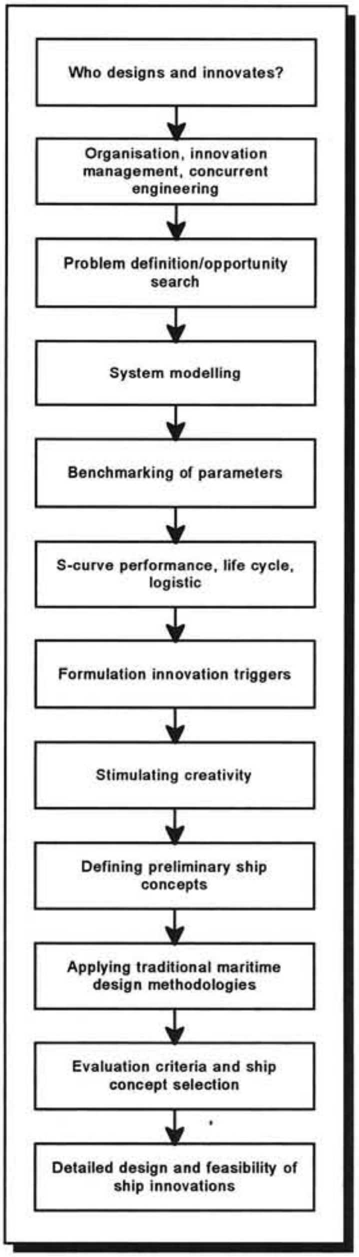


Figure 1: Structure of DIS

The double hull tanker has been triggered by the U.S. Oil Pollution Act 1990, which objective is to minimise oil spills and protect the marine environment from shipping. It is a well known fact that in shipping around seventy percent of the accidents arise from human failures and not technical failures. The double hull tanker does not solve 70% of the potential pollution problems from tankers along U.S. coastal waters and ports. If one counts the costs of the transformation of the tanker fleet into a double hull fleet, and measure the relative effectiveness of the solution with other potential measures, than the focus of OPA90 is not so clear. Consider for example vessel traffic systems in the U.S., which are virtually nonexistent. The most pressing example is the Houston Ship Channel, where the Coast Guard has to rely on their eyes and ears to guide the highly dangerous chemical tankers safely through this passage, without the aid of radar and the like. This seems unbelievable in almost 21st century America, but yet it is the disappointing truth. When there is a heavy fog, the port is either paralysed or the movements of ships are extremely dangerous as the Coast Guard can only hear their horn blow.

So from a cost-effective point of view, the OPA90 act should rather have focused on the upgrading of the VTS-systems in the U.S., but than the burden of investment would have fallen on the U.S. ports, which is more difficult to implement than taking a measure which only affects foreign shipowners. They have no lobby power in Congress and do not represent any votes.

The second example of a possible wrong problem definition is the safety of passenger ferries and ro-ro's. Ships without transverse and/or longitudinal bulkheads have a natural limited damage stability. They capsize easily when punctured and flooded. That is why the SOLAS convention was created as the first international piece of maritime design legislation after the sinking of the *Titanic*. The *Harold of Free Enterprise* and *Estonia* drama's led to the questioning of the correctness of the current design rules for these ships. The proposed amendments to the rules seem to be restricted to passenger/freight ferries only. The freight-only ro-ro's are for the time being left out of the revision. Most of the accidents have happened just with this type of ship.

Therefore the whole ship concept should be revised fundamentally including freight-only ro-ro's in such a way that the damage stability comes up to the highest standards.

The problem focus and consequent definition is too narrow from the start and will lead to sub-optimal solutions, which are only 'cures for the symptoms'.

This point of view has also been voiced by BIMCO president F. Lorentzen, stating at their 1995 general meeting that *"too much regulatory effort was designed to cope with the consequences of marine accidents, rather than to prevent them in the first place."*(LL 31.5.95)

A design project can always be defined in many ways and it is the challenging task of the project team to come up with as many perspectives and definitions as possible.

This task is harder, when the trigger for the design project has not been a problem, but is rather the uneasy feeling of looking for opportunities. How does one operationalise such a task?

The standard approaches involve a discussion with the managers of the shipping company during which the following basic questions are asked and answered:

- Define the objectives/mission of the company; this forms the background (Gestalt) against which the problems/opportunities take shape; without objectives there are no problems or opportunities.
- Next, the managers should list all the problems/opportunities associated with the design task under consideration; these problems should then be divided into two categories: internal problems and external problems, which cannot be influenced by the management such as the freight rates in the tanker market;
- Finally, the managers should filter these problems and classify them into basic-problems and subproblems, which results in a problem-hierarchy. This procedure is illustrated in **Figure 2.**

What might be useful as a next step is the creation of an integral or (w)holistic picture of the problem/opportunity through the sketching of a dynamic model, in which all the variables are drawn and the causal loops show the interactions.

Often it is a good idea to consider the problem from a higher level, first ignoring the present situation. According to Stian Erichsen in *"Management of Marine Design"*, innovations are often prohibited by the initial formulation of the required design. The objective of a design job must be expressed so that no possible solution is excluded.
Shipowners are often concentrated on one solution. When they express the aims of the design, they may encourage particular solutions or introduce conditions that restrict the possible solutions to some familiar type. Therefore, it may be worthwhile to spend some effort on reformulating the design aims. "*The aim should express the design objectives in a way that clearly states the purpose of the design but also leaves the options open for the wide variety of solutions which may exist.*" This increases the freedom of choice and encourages creativity and inventiveness. Abstract formulations can be used at any stage in the design process and for any design object.
Erichsen gives several examples that clearly express what he means. Two of them are:

- *Original*: Design a bulk carrier where: D = x, B = y, L = z, d = t, V= h
  Reformulation: Design the transport of x tons of iron ore per year from point A to point B. Or design a bulk carrier that can be traded in the market for twelve years and can call at all important ports and that does not exceed Panamax limits.

- *Original*: Design a replacement vessel for M/S XXX
  Reformulation: Design a vessel that can provide the same transport at M/S XXX and is adaptable to the expected development in techniques and business.

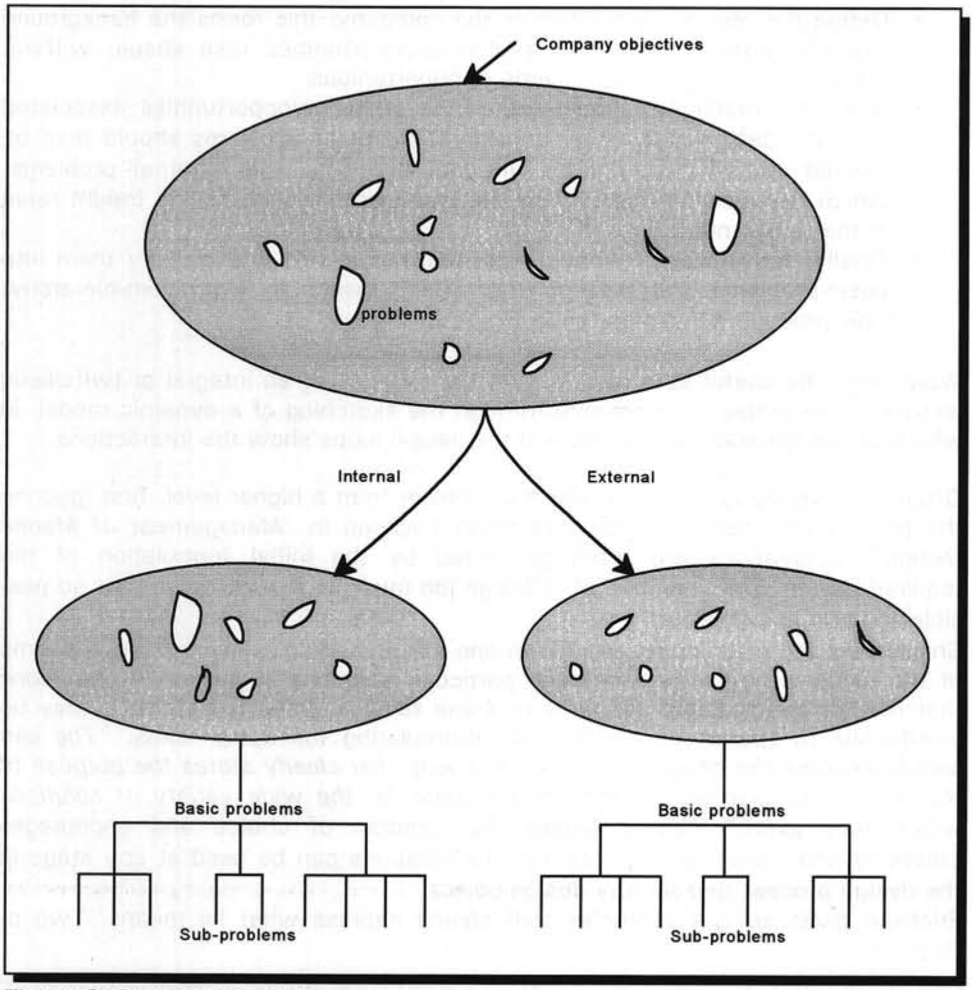


Figure 2: Problem hierarchy

Erichsen illustrates this with the picture in **Figure 3**. The 'demand for a tanker' is an aim formulation encouraged by existing solutions. 'Providing energy at certain places' is a more abstract formulation.

Step 4 - System modelling

The design innovation project, once defined in general terms, should now be focused on areas which are under control, or can be influenced by the company. It is therefore necessary to start the modeling process with a clear definition of the project (model) boundaries or limits. The boundary of the model is

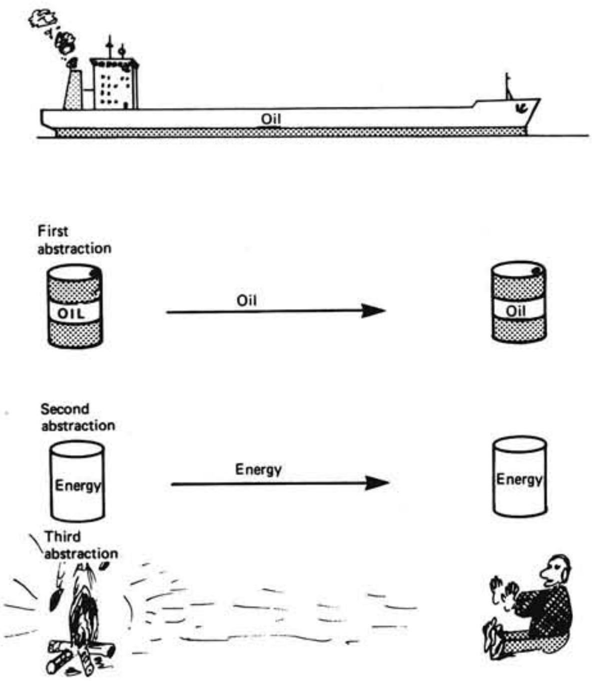


Figure 3: Example of abstract reformulations

determined by the objectives of the model and the design objective of the innovation project.

The shipping company only models the internal problems as endogenous variables, and treats the external problems as exogenous variables. For example, if the design innovation project is focused on the creation of a shallow draught Suezmax oil tanker, like the case-study of Platou's ECO-tanker, than it is not useful to make a detailed shipping model of the transport of oil through the Suez canal, relate this to the world seabourne oil flows, and relate this in return to the development in the demand for oil, and ultimately to the relationship between world economic growth and demand for energy, in particular oil.

This will shift the effort of the modeling work into areas way beyond the competence of the shipowner, and which is anyway of little value to the design innovation effort.

A better way to treat exogenous variables is to test the model for changes in key-external variables; what is the impact of a change on model behaviour; if the impact is important, spend some extra time on a more detailed analysis in order to assess the risk on the viability of the design innovation project as a whole. **Figure 4** illustrates the approach, while the example of the system dynamics oil tanker model in **Chapter 18** shows the causal diagram building and boundary selection.

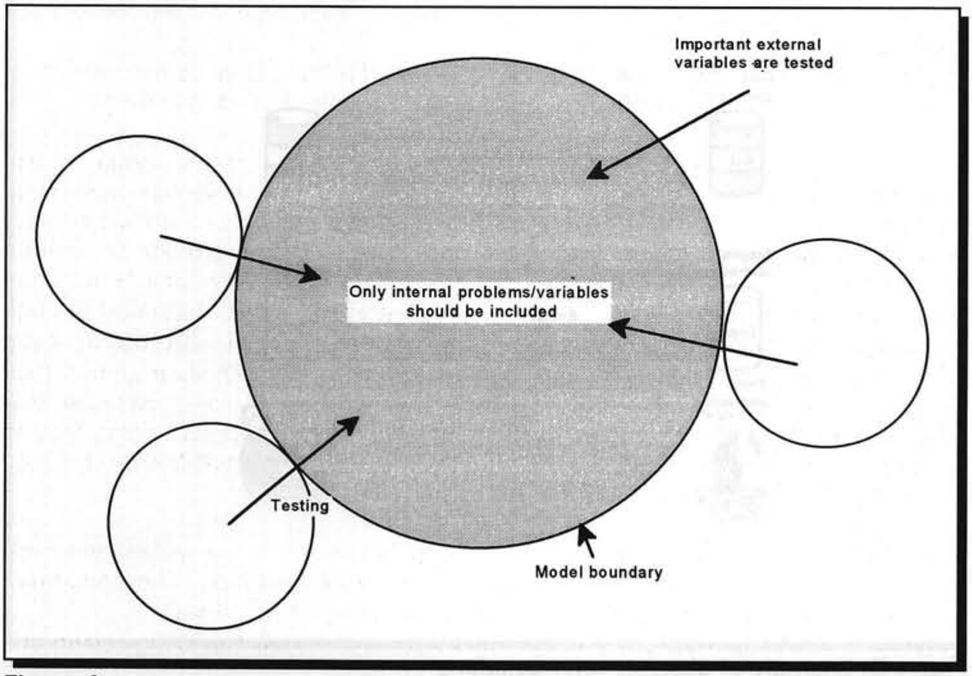


Figure 4

The overall conceptual model of the design task will always become very complex; a complexity which often can not be handled integrally. Looking at a new ship concept, the design task may be divided into for example the cargo handling system, the hold structure, the hull design, etc. The case-study on innovation in forest products shipping (reels-on-wheels-system) illustrates the breaking down of the overall design project into different sub-tasks or smaller pieces (**Chapter 19**).

Many variables in a model are aggregated and therefore the models do not lend themselves to address detailed questions. Besides, managers like to recognise enough detail in the model, it should resemble their mental model, otherwise they become suspicious of the terminology and the structure, and the confidence and acceptance levels will go down with it.

The sub-models may thus become sub-design projects, which can be handled by different design teams. Naval architects should be involved in the hull form, hydrodynamics, propulsion system and machinery, etc.; cargo handling experts should be involved in new handling processes, hold or tank structures. The example of the chemical tanker based on the cylinder tank type containment system is a good example of the 'division of labour' in a design project.

It should be supervised of course that not every design group goes into its own direction; that is the job of the project leader, the spider in the concurrent engineering project.
It is also useful to apply value analysis techniques in this phase of the project, in order to set priorities and define the problem/opportunity search hierarchy.

The modeling effort will also highlight the driving forces of the model; these should be addressed urgently, as they may control the whole design innovation projects. Each variable should be carefully discussed and especially when new concepts are defined, and it will require a positive, creative attitude to venture into uncharted territory. For example, a design project of a chemical tanker may define the cost of cargo claims as a result of contamination of the cargo through cracking in the stainless steel tanks as a variable of the model, and thus an issue to be dealt with in the new design. The generic problem definition should than be formulated as "*how can we design a tank (form, structure, material) that does not crack at all?*". Although this may seem a trivial question, it may lead to consider new tank forms like the cylinder tank type, or the Stolt-Nielsen solution of the longitudinal cofferdams.

The model will also indicate the relationship between the variables and from this, the critical factors and the critical paths may be identified. The concurrent engineering design team will set priorities on the basis of this insight.
Besides, a model is a powerful communications tool within the design team and between the team and the rest of the organisation.
The other benefits from modelling the design innovation project are:

- ***Information*** that is necessary to fill the model variables and parameters, is usually not readily available, while the 'educated guess' from the managers is often very far from reality. The administrative procedures are consequently changed in order to provide the data in the future. An example is the production of slops from tank washing on chemical tankers, which can be found in the book Innovation in Chemicals Shipping. Very few managers within chemical shipping companies are able to estimate within a margin of 50% the actual slops production on their ships, as it never was their concern. The example of P&I claims as a result of cargo contamination because of cracks in the tanks of a chemical tanker is another example; very few managers are a aware of the real cost of cracking, as the insurance claims are handled by a department which in general does not report this kind of 'back office' information to the topechelons. The introduction of Quality Management Systems and the eminent obligation to administer the International Ship Management Code within shipping companies has helped to get companies to focus on these kinds of 'trivial data' signals. Signals that can become triggers for innovation.

- The systematic identification of the important variables that affect the design (and the company) through a model building process, will help to strengthen the ***manager's mental model***.

- Managers are often absorbed in their day-to-day business, especially in shipping, as there is always bad weather, a strike in a far away port, broken down equipment, a bad debtor, an unhappy banker, and the like to take care of. A model of a design innovation project pins them down to think about tomorrow and the future, and not only about tomorrow. This will help the ***managers to think ahead***, make abstractions and aggregations.

- If the model is not only verbal (causal loop diagram), but also translated into quantitative terms, it can be used to translate it into a ***simulation*** model of the design innovation project. The manager can thus easily play around with the model himself, which may increase his confidence level, and consequently make him more liable to accept the final outcome.

- The results of the modeling process are constantly fed back to the design team, which will lead to modifications of the original model, as new insights and ideas are triggered. Gradually the process will ***converge over time towards a solution***.

The model is thus the common tool, or language of the design team through which evaluation of current and new ideas are tested and selected. **Figure 5** illustrates this process.

Step 5 - Benchmarking of parameters

Design innovation in shipping is done by companies to create a competitive advantage; its aim is to increase the relative performance of the shipping company in comparison with other operators in the sector. Performance can be translated into indicators, as was shown in the case studies on Panamax bulk carriers and container ships.

The modeling effort of the design innovation project as discussed above, provides the variables and parameters that are the indicators on the basis of which the performance can be measured. This process, which is called benchmarking, is an essential instrument in the design process. It provides an objective basis to compare performance within a company (as demonstrated by

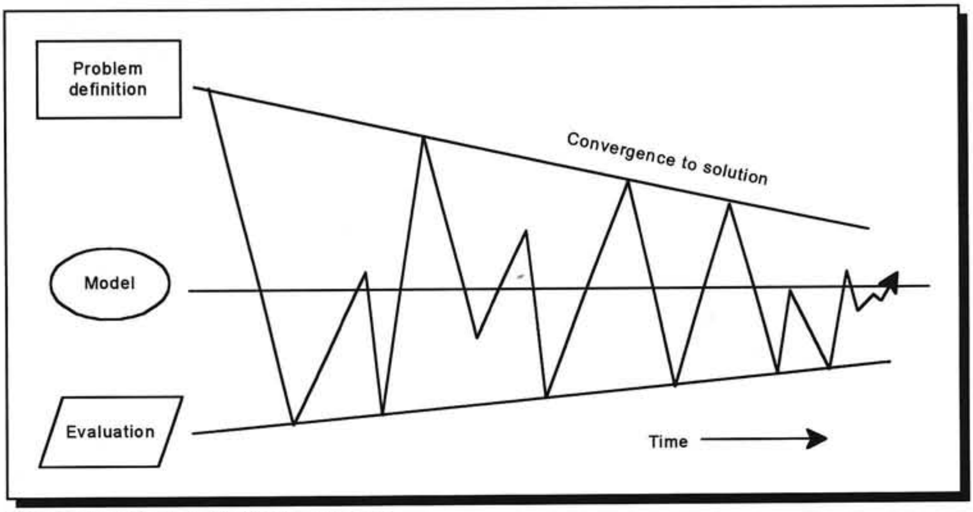


Figure 5: The modelling process

Step 5 - Benchmarking of parameters

Design innovation in shipping is done by companies to create a competitive advantage; its aim is to increase the relative performance of the shipping company in comparison with other operators in the sector. Performance can be translated into indicators, as was shown in the case studies on Panamax bulk carriers and container ships.

The modeling effort of the design innovation project as discussed above, provides the variables and parameters that are the indicators on the basis of which the performance can be measured. This process, which is called benchmarking, is an essential instrument in the design process. It provides an objective basis to compare performance within a company (as demonstrated by the Jo Tankers ship performance ranking, discussed in section 13.6) and between companies in the sector as a whole (see Panamax bulk carrier case-study, section).

Most of the companies have only looked at financial performance indicators, related to the balance sheet ratios and profit & loss accounts. Financial information is very important, but it does not provide a clue about operational performance. The benchmarking exercise will help shipping companies to extend the way they measure their own performance and that of the competition.

Step 6 - S-curve performance. life cycle, logistic

Benchmarking of the performance of shipping companies indicates the relative performance but not the absolute performance levels that can ultimately be attained. In order to assess these ultimate performance limits, it is necessary to

technology and speculate about the shifts in technology; this may also lead to new limits and a change of the model boundaries and even the structure.
Model building, benchmarking and S-curve assessment set the stage for the creative phase in the design innovation project. It can be compared with the 'long march' which is sometimes frustrating as it gives the design team the impression that they are not creatively working on innovation. It can however be compared with the warming up of athletes; this is important to perform, without it, they ruin their muscles and never achieve the highest results.

Step 7 - Formulating innovation triggers

This step is a logical consequence of the previous steps, and it can be structured around the themes proposed in section 7.3. These are:

- Physical laws triggers;
- Geographical conditions triggers;
- Economic parameters triggers, such as maximisation of revenues/minimisation of ballast voyages, economy of scale, minimisation of capital investment, running, voyage, port, and cargo handling costs;
- Regulations triggers;
- Related sector triggers.

Once the triggers have been identified and quantified, they form the basis of creative problem solving groups and techniques.

Step 8 - Stimulating creativity

Each trigger can be taken as a basis for the application of creativity techniques. The design team should have at least one person assigned to the role of independent facilitator, who keeps track of the methodological aspects of the creativity process and who is not involved in the actual design process. This facilitator should have followed a formal training in the use and scope of the various techniques. A training that should have preceded the formation of the design team. The facilitator may propose techniques which are particularly suited for a certain design task. For example, if the team's job is to develop a low resistance, very fast craft, than it may study the design of torpedoes. The Russians have developed an innovative torpedo, which creates an air cushion around it shell, which lowers its resistance and increases its speed to 200 knots (compared to 80 knots for conventional torpedoes).
Sometimes free association, followed by technological analogies, followed by morphological analysis and/or ideacard-brainwriting. Thus, divergent and convergent techniques are used, depending on the subject and the mood of the design team. Negative brainstorming is a very liberating effort if the design team is stuck and deactivated. The facilitator should therefore also be an individual with a certain sensitivity towards the group dynamics.

suited for a certain design task. For example, if the team's job is to develop a low resistance, very fast craft, than it may study the design of torpedoes. The Russians have developed an innovative torpedo, which creates an air cushion around it shell, which lowers its resistance and increases its speed to 200 knots (compared to 80 knots for conventional torpedoes).
Sometimes free association, followed by technological analogies, followed by morphological analysis and/or ideacard-brainwriting. Thus, divergent and convergent techniques are used, depending on the subject and the mood of the design team. Negative brainstorming is a very liberating effort if the design team is stuck and deactivated. The facilitator should therefore also be an individual with a certain sensitivity towards the group dynamics.

At the same time, the individual members of the team should be encouraged to use their own strength independently in order to come up with ideas. Some like to design-by-drawing, while others need a walk on the beach, or a stiff drink to tap their creative resources.

The design team may also use advanced Group Decision Rooms for their creativity sessions; this facilitates parallel and anonymous brainstorming with a relatively large group of people, roughly twice the number as used in normal group session. **Figure 6** shows a picture of such a Group Decision Room at the Faculty of Systems Engineering, Policy Analysis & Management of the Delft University of Technology.

Figure 6: Group Decision Room

Step 10 - Applying standard maritime design methodologies

This step is more or less equivalent to the standard design methodologies as discussed in **Chapter 3**. Standard calculation programmes are not always applicable in case the design innovation is so novel that the current routines can not be transformed. The same is true for the classification rules and regulations; it is therefore necessary to discuss new concepts in an early stage with the classification society's representatives. It should be avoided that newness is aborted because it requires a change in the design rules and regulations.

Step 11 - Evaluation criteria and ship concept selection

Performance indicators which have led to the innovation triggers, can now be used to evaluate the new designs in more detail. The important criteria should be met and a balance should be sought between primary and secondary design parameters. These are not always of monetary nature, but may also be the damage stability coefficients. This process should lead to the selection of one design.

Step 12 - Detailed design and feasibility of innovations

The selected design should now be engineered in detail, and the detailed costs and benefits of the ship should be established. The standard operational, economic and financial feasibility studies will lead to an overall evaluation of all the relevant aspects. On this basis the management of the company can decide to perform further market analysis, or approach shipyards for actual quotations.
They may also decide to try to patent certain novelties in the design. This should be done, before the outline specification is sent to the shipyards.

Overview of the entire Design Innovation in Shipping methodology.

The entire DIS process will probably take no more than six months and is schematically shown in **Figure 7**. This pre-supposes that various elements have already been researched in advance, such as the benchmarking of the shipping companies performance, as this takes a lot of time, due to a limited availability of information.

The DIS methodology is not cast in iron; it may however become an improvement over existing design methodologies. But then again, this may be overtaken by better propositions, as "*the only constant (in shipping) is change*"!

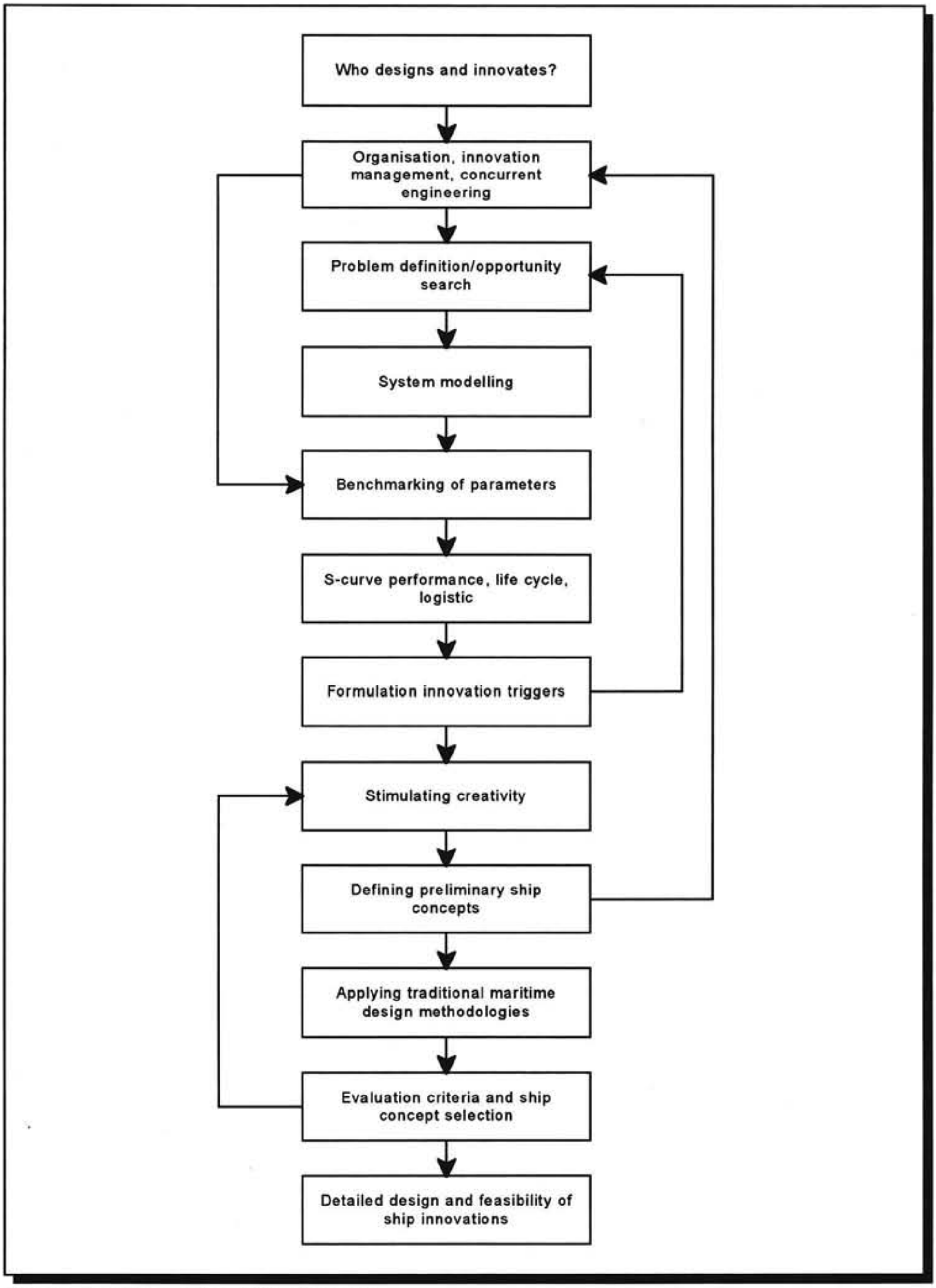


Figure 7: The entire DIS process

CHAPTER 26: CHAPTER NOTES

INTRODUCTION

H.L. Houtzager et al, *"Delft en de Oostindische Compagnie"*, Rodopi BV, Amsterdam, 1987, 221 pages

H. Baudet, *"De lange weg naar de Technische Universiteit Delft; De Delftse ingenieursschool en haar voorgeschiedenis"*, Sdu Uitgeverij, Den Haag 1992, 575 pp.

J.C. Blankert, *"Ondernemend Nederland in een wereld aan wetenschap en technologie"*; inleiding ter gelegenheid van het VNSU-lustrumseminar, 7.6.95

"Inhaalrace in technologie nodig"; NRC Handelsblad 13.6.95

CHAPTER 1: NATURE OF ENGINEERING DESIGN

Figure 5: Lloyds List 19.5.95, The motorship, Juli 1995

CHAPTER 2: THE NATURE OF ENGINEERING DESIGN

E.S. Ferguson, *"Engineering and the Mind's Eye"*, The MIT Press, London, 1992, 241 pages

CHAPTER 3: CURRENT DESIGN METHODOLOGIES

Society of Naval Architects and Marine Engineers, *"Principles of Naval Architecture"*, Society of Naval Architects and Marine Engineers, New York, 1967

C. Georgescu, H. Boonstra, F. Verbaas, *"Concept Exploration Model for multi-purpose/container carriers"* , Schip en Werf, de Zee, May and June 1992

K. Levander, M. Jahkola, T. Raouta - Wärsilä Helsinki Shipyard, *"Wärtsilä Seakey; mission based ship design"*

H. van Keimpema, *"Ontwerpen van schepen IV - Voorontwerp met behulp van een P.C."* , Delft University of Technology, Delft

C. Gallin, F. Härtel, H. van Keimpema, *"Ontwerpen van schepen I"* Delft University of Technology, Delft, November 1988

CHAPTER 4: INVENTIONS AND BASIC INNOVATIONS IN SHIPPING

E. de Bono (Ed), *"Eureka, an illustrated History of Inventions from the Wheel to the Computer"*, Hol, Rinehart and Winston, New York, 1979, 248 pages

C. Marchetti, *"Society as a learning system: discovery, invention, and innovation cycles revisited"*, Technological Forecasting and Social Change, volume 18, 1980, p. 267-282

R. Gardener, B. Greenhill (Ed), *"The Advent of Steam; the Merchant Steamship before 1900; Conway's History of the Ship"*, Conway Maritime Press Ltd. London, 1993, 190 pages

D.R. MacGregor (Ed), *"Merchant Sailing Ships 1775-1815 sovereignty of sail"*, Conway Maritime Press Ltd, London, 1985, 224 pages

D.R. MacGregor (Ed), *"Merchant Sailing Ships 1850-1875 Heyday of Sail"*, Conway Maritime Press Ltd., London, 1984,256 pages

R. Gardiner (Ed), *"The Golden Age of Shipping, The Clasis Merchant Ship 1900-1960"*, Conway Maritime Press, London, 1994, 192 pages

R. Gardiner (Ed), *"The Shipping Revolution, The Modern Merchant Ship"*, Conway Maritime Press Ltd, London, 1992, 208 pages

"Shipbuilding and Marine Engineering in Japan 1995", Japan Ship Exporters Association and The Shipbuilders' association of Japan, 1995, 252 pages

A selection of other books, which provide the reader with some insight into the devleopment of (mainly Dutch shipping and technology):

W. Wouters (Ed), *"Van Koninklijke Afkomst"*, Shell Tankers BV, Rotterdam, 1983, 172 pages

B. Oosterwijk (Ed), *"Op een koers"*, Koninklijke NedLloyd Groep NV, Rotterdam, 1988, 387 pages

W.J.J. Boot (Ed), *"De Nederlandse Radar Stoomvaart"*, De Alk BV, Alkmaar, 1990, 128 pages

B. Macdermot (Ed), *"Ships Without Names, the story of the Royal Navy's Tank Landing Ships of World War Two"*, Arms and Armour Press, London, 1992, 128 pages

E.S. van Eyck van Heslinga (Ed), *"Van Compagnie naar koopvaardij, de scheepvaartverbinding van de Bataafse Republiek met de koloniën in Azië 1795-1806"*, De Bataafsche Leeuw, Amsterdam, 1988, 320 pages

A. Lagendijk, *"Van de Willem III tot de Willem Ruys"*, Van der Loeff, Enschede, 1983, 160 pages

B.W. Scholten, F.M.E.W. Haalmeijer (Ed), *"Rotterdamse Lloyd"*, De Boer, Houten, 1988, 126 pages

L.L. von Münching (Ed), *"Koninklijke Hollandsche Lloyd, wel en wee van een Amsterdamse Rederij"*, De Alk BV, Alkmaar, 1990, 160 pages

H.J. Korver (Ed), *"Koninklijke Boot, beeld van een Amsterdamse scheepvaartonderneming"* 1856-1981, De Bussy Ellerman Harms, Amsterdam, 1981, 207 pages

H.J.G.W. Leerink (Ed), *"Maritiem Profiel, voorsprong door specialisatie"*, Otto Cramwinckel, Amsterdam, 1991, 229 pages

H.W. Lintsen et al, *"Geschiedenis van de Techniek in Nederland, de wording van een moderne samenleving 1800-1890"*, Walburg Pers, Zutphen, 1993, 352 pages

CHAPTER 5: TECHNOLOGICAL INNOVATION AND ECONOMIC GROWTH

B. Blackwell, S. Eilon, *"The Global Challenge of Innovation"*, Butterworth-Heinemann Ltd, Oxford, 1991, 220 pages

R. Rothwell, W. Zegveld, *"Reindustrialization and Technology"*, Longman Group Limited, Essex, 1985, 282 pages

H. Håkansson (Ed), *"Industrial Technological Development; a network approach"*, Croom Helm Ltd. London, 1987, 234 pages

D.C. Mowery, N. Rosenberg, *"Technology and the pursuit of economic growth"*, Cambridge University Press, 1989, 330 pages

T. Sandven, K. Smith, *"Innovation activities and industrial structure: industry and R&D in a comparative context"*, European Innovation Monitoring System, Publication No 01, 1994, 54 pp.

A. Wyckoff, *"Investment, innovation and competitiveness: sectorial performance within the Triad"*, European Innovation Monitoring System, Publication No 02, 1994, 94 pp.

C. Freeman (ed), *"The Economics of Industrial Innovation"*, C. Nicholls & Company Ltd. Manchester, 1974, 409 pages

A. Heertje (Ed), *"Innovation, Technology, and Finance"*, Basil Blackwell Ltd. Oxford, 1988, 211 pages.

M.E. Porter, *"The Competitive Advantage of Nations"*, The Macmillan Press Ltd., London, 1990, 855 pages

CHAPTER 7: S-CURVES AND INNOVATION IN SHIPPING

E.M. Rogers, *"Diffusion of Innovations"*, The Free Press, a Division of Macmillan Publishing Co., Inc., New York, 1962, 453 pages

R.N. Foster, *"Innovation, the Attacker's Advantage"*, Summit Books, Inc., New York, 1986, 316 pages

R. Foster, *"Innovatie: de aanval is de beste verdediging"*, L.J. Veen B.V., Utrecht, 1987, 255 pages

"Milieubeheer is volwassen geworden", NRC Handelsblad, 8.5.95

L.A. van Gunsteren, *"Management of Industrial R & D; a viewpoint from Practice"*, Eburon Publisher, Delft, 1992, 213 pages

C. Waldhelm, *"Marine propulsion: industrial derivative gas turbines"*, Shipbuilding Technology International ´95, London, p.92-95

"Fast Monhull: Fast Container Vessel, Fast Trailer Vessel", Blohm + Voss, Hamburg, March 1995

L. Moret, *"Krachten op lading aan boord van containerschepen"*, Schip & Werf de Zee, april 1995, p.42-43

R.S. Platou, *"Tube Tanker or Eco Tanker"*, Oslo, November 1987

J. Deerberg, *"Waste management on ships: state-of-the-art"*, Shipbuilding Technology International ´95, London, p.147-150

S. Thomas, *"Tonnage Measurement"*, Seatrade Review, April 1994

CHAPTER 8: BENCHMARKING IN SHIPPING

G.H. Watson, *"Strategic Benchmarking; how to rate your Company's Performance against the World's Best"*, John Wiley & Sons, Inc., Toronto, 1993, 268 pages

K.A. Ingle, *"Reverse Engineering"*, McGraw-Hill, Inc., New York, 1994, 240 pages

A. Rolstadas (Ed), *"Benchmarking - Theory and Practice"*, Chapman & Hall, London, 1995, 396 pages

N. Wijnolst, M. Bartelds, *"Analysis of the Panamax bulkcarrier chartermarket 1989-1994 in relation to the design characteristics"*, Delft University Press, 1995, 211 pages

N. Wijnolst, E. Hoek, *"Analysis of the containership chartermarket 1983-1992 in relation to the design characteristics of containerships"*, Delft Univeristy Press, 1993, 253 pages

CHAPTER 9: DIFFUSION OF INNOVATION

E.M. Rogers, *"Diffusion of Innovations"*, The Free Press, a Division of Macmillan Publishing Co., Inc., New York, 1962, 453 pages

C. Marchetti, *"A forecasting model for research and innovation activities in selected areas: a support for strategic choices,"* Paper at the International Course on Research and Innovation Management, UNIDO and ICS, Venice, 1991

J.L. Casti, *"Explaining a Paradoxical World Through the Science of Surprise"*, HarperCollins Publishers, Inc., New York, 1994, 320 pages

C. Marchetti, *"Society as a learning system: discovery, invention, and innovation cycles revisited"*, Technological Forecasting and Social Change, volume 18, 1980, p. 267-282

CHAPTER 10: INNOVATION IN SCIENCE AND TECHNOLOGY

J.A. Bell, J.F. Bell, *"Views of knowledge and system dynamics: An historical perspective and commentary,"* paper presented at a System Dynamics Conference

T.S. Kuhn, *"The Structure of Scientific Revolutions"*, The University of Chicago, 1962, 210 pages

J.L. Casti, *"Paradigms Lost; images of man in the mirror of science"*, Scribners, Macdonald & Co Publishers Ltd., London, 1989, 565 pages

H.F. Cohen, *"The Scientific Revolution; a Historiographical Inquiry"*, The University of Chicago Press, 1994, 662 pp

"Germanischer Lloyd, Internationales Register, 1867-1992", Germanischer Lloyd, Hamburg, 1992, 292 pages

"ABS SafeHull: Technical Information", New york, 1994, 25 pp.

EEIG Unitas, *"On Line Class System, a new classification concept"*, 1995

CHAPTER 11: INNOVATION AND THE FIRM

H.I. Ansoff, *"Corporate Strategy"*, McGraw-Hill, U.S.A., 1965, 284 pages

H.I. Ansoff, E.J. McDonnell, *"Implanting Strategic Management"*, Prentice Hall International Ltd., Hertfordshire, 1990, 520 pages

T. Peters, *"Thriving on Chaos, handbook for a management revolution"*, Alfred A. Knopf, Inc., U.S.A., 1987, 561 pages

M. Stopford, *"Maritime Economics"*, Unwin Hyman Ltd, London, 1988, 413 pages

M.E. Porter, *"Competitive Advantage, creating and sustaining superior performance"*, The Free Press, a division of Macmillan, Inc., New York, 1985, 557 pages

T. Wergeland, *Current strategic issues for Norwegian Shipping*, Centre for International Economics and Shipping, Bergen, draft, 27.6.93, 26 pp.

MERC-MDS Transmodal, *"Large Containerships; economics of 6000+ TEU vessels"*, May 1994, restricted study for the Port of Rotterdam

"The next step in containership design", Lloyd´s List: German Maritime Technology, May 1995, p.12-13

N. Wijnolst, *"Economy of scale in containerships and containerlines; past and future"*, Paper at the 5th World Container & Intermodal Congress, 3-5 June 1992, Rotterdam

CHAPTER 12: MANAGEMENT OF INNOVATION AND BUSINESS SYSTEMS ENGINEERING

T. Peters, *"Thriving on Chaos, handbook for a management revolution"*, Alfred A. Knopf, Inc., U.S.A., 1987, 561 pages

V. Nolan, *"The innovator's handbook; the skills of innovative management. Problem solving, Communication and Teamwork"*, Penguin Books, London, 1987, 325 pages

P.J. van Delden (Ed), *"Innoveren in het bedrijf"*, Samson Uitgeverij, Alphen aan den Rijn, 1982, 188 pages

A.J. Cozijnsen, W.J. Vrakking (Ed), *"Handboek voor strategisch innoveren. Een internationale balans"*, Kluwer, Deventer, 1986, 330 pages

B.C. Twiss (Ed), *"Managing Technological Innovation"*, Longman Group Limited, London, 1974, 237 pages

G.H. Watson, *"Busines Systems Engineering, managing breakthrough changes for productivity and profit"*, John Wiley & Sons, Inc., Toronto, 1994, 287 pages

J.D. Morecroft, J.D. Sterman (Ed)," *Modeling for Learning Organizations"*, Productivity Press, Portland, Oregon, 1994

P. Gu, A. Kusiak (Ed), *"Concurrent Engineering; methodology and applications"*, Advances in Industrial Engineering, 19, Elsevier, Amsterdam, 1993, 330 pages.

R. de Graaf, E.J. Sol, *"Assessing Europe's readiness for Concurrent Engineering in Concurrent Engineering: Research and Applications Conference Proceedings"*, A.J. Paul and M. Sobolewski (eds.), 29-31 August 1994

CHAPTER 13: DESIGN METHODOLOGIES

N.F.M. Roozenburg, J. Eekels, *"Produktontwerpen, Structuur en Methoden,"* Lemma BV, Utrecht, 1991, 393 pages

H.H.C.M. Christiaans, *"Creativity in Design, the role of domain knowledge in designing"*, Lemma BV, Utrecht, 1992, 154 pages

E. Torenbeek, *"Synthesis of subsonic airplane design"*, Delft University Press, 1981

E. de Bono (Ed), *"Opportunities"*, Penguin Books Ltd. Harmondsworth, Middlesex, England, 1978, 252 pages

S.G. Isaksen et al, *"Creative Approaches of Problem Solving"*, The Creating Problem Solving Group, Buffalo, 1994, 396 pages

A.F. Osborn, *"Applied Imagination, principles and procedures of creative problem-solving"*, Charles Scribner's sons, New York, 1953, 417 pages

N. Roberts et al, *"Introduction to computer simulation: The system dynamics approach,"* Addison-Wesley, Reading, Mass., 1983

M.R. Beheshti (Ed), *"Systematisch Ontwerpen"*, Course Notes, Faculty of Civil Engineering, Delft University of Technology, 1992

J.J. Evers, *"How to read activity/factor-diagrams"*, Oestgeest, 1992

G.J. Colquhoun et al, *"The use of IDEFo to link design and manufacture in a CIM environment"*

Logistic Engineering in the Faculty of Mechanical Engineering and Marine Technology, Delft, 1992

S. Cooperman, *"Freight Utilization and Revenue Index"*, Stolten, April 1995, p.15

"Vessel of the year 1994: Jo Palm", JO Journal, Volume 36, April/May 1995

CHAPTER 15: OPTIMISATION OF SMALL GASTANKERS

This chapter is based on:
ir. T. Valentijn, master thesis, Faculty of Mechanical Engineering and Marine Technology, Delft University of Technology, 1989

CHAPTER 16: SEA-RIVER CONTAINER SHIP

This chapter is based on a project of the author in collaboration with various parties, in particular Verolme Shipyard Heusden, 1986

CHAPTER 17: TUG/BARGE CAR CARRIER FOR THE RHINE

This chapter is based on:
ir. W. van Leeuwen, master thesis, Faculty of Mechanical Engineering and Marine Technology, Delft University of Technology, 1992

CHAPTER 18: CYLINDER TANK TYPE CHEMICAL TANKER

N. Wijnolst (Ed), *"Innovation in chemicals shipping; port and slops management"*, Delft University Press, 1994, 320 pages

This chapter is based upon a project by the author in collaboration with ir. E. Vossnack and Holvrieka-Nirota B.V. on behalf of a large chemical tanker company, 1992

CHAPTER 19: DESIGN OF AN INTEGRATED OIL SUPPLY SYSTEM

This chapter is based on:
R.G. Coyle, *"Management System Dynamics"*, System Dynamics Research Group University of Bradford, John Wiley & Sons Ltd., London, 1977, 463 pages

CHAPTER 20: INNOVATION IN FOREST PRODUCTS SHIPPING

N. Wijnolst, R. van der Lugt, *"Innovation in Forest Products Shipping; the Reels on Wheels system"*, Delft University Press, 1993, 189 pages

CHAPTER 21: INNOVATION IN SHORTSEA SHIPPING

N. Wijnolst et al, *"Innovation in shortsea shipping: selfloading and unloading unitload shipsystems (S-curve shift in the handling of unitloads)"*, Delft University Press, 1993, 260 pages

N. Wijnolst et al, *"Multimodal Shortsea Transport Coastal Superhighway; indispensable and free link in the European transport network"*, Delft University Press, 1994, 194 pages

CHAPTER 22: DECISION SUPPORT SYSTEM FOR THE PLANNING OF CHEMICAL TANKERS

This chapter is based on:
D. Antvelink, master thesis, Faculty of Mechanical Engineering and Marine Technology, Delft University of Technology, 1995

CHAPTER 23: THINKING, CREATIVITY AND INNOVATION

A. Koestler, *"The Act of Creation"*, Pan Books Ltd, London, 1975, 491 pages

A. Rupert Hall, *"Isaac Newton, Adventurer in Thought"*, Blackwell Publishers, Oxford, 1992, 468 pages

C.D. Andriesse, *"Titan kan niet slapen; een biografie van Christiaan Huygens"*, Contact Amsterdam, 1993, 414 pages

A. Pais, *"Einstein lived here"*, Oxford University Press Inc., New York, 1994, 282 pages

N. Baldwin, *"Edison, inventing the century"*, Hyperion, New York, 1995, 531 pages

T.A. Bass, *"Reinventing the Future; conversations with the World's Leading Scientists"*, Addison-Wesley Publication Company, 1994, 249 pages

J. Gleick, *"The Life and Science of Richard Feynman"*, Vintage Books, New York, 1992, 531 pages

C. Kennedy, *"Guide to the Management Gurus; shortcuts to the ideas of leading management thinkers"*, Business Books Limited, London, 1991, 172 pages

J. Diebold, *"The Innovators; the discoveries, inventions, and breakthroughs of our time"*, Penguin Books USA Inc., New York, 1991, 303 pages

C. Marchetti, *"Action curves and clockwork geniuses"*, Working Paper 85-74, International Institute for Applied Systems Analysis, Laxenburg, Austria, October 1985,

I.A. Taylor, J.W. Getzels (Ed), *"Perspectives in Creativity"*, Aldine Publishing Company, Chicago, 1975, 353 pages

J.P. Guilford, *"Way behond the IQ"*, The Creative Education Foundation, Inc., New York, 1977, 192 pages

E. de Bono, *"Teaching Thinking,"* Maurice Temple Smith Ltd., London, 1976, 238 pages

CHAPTER 24: STIMULATING CREATIVITY IN THE DESIGN PROCESS

H. Geschka, U. von Reibnitz, *"Eine Anleitung zum Arbeiten met Methoden der Ideenfindung; Vademecum der Ideenfindung"*, Battelle-Institut e.V., Frankfurt, , 120 pages

I. Svantesson, *"Mind Mapping & Memory, powerful techniques to help you make better use of your brain"*, Swan Communications Limited, Aucklans, New Zealand, 1989, 104 pages

E. de Bono, *"Lateral thinking for Management"*, McGraw-Hill Book Company Ltd., Maidenhead, Berkshire, 19.., 225 pages

D. Gause, J. Weinberg (Ed), *"Are your lights on?"*, Ethnotech, Inc., Lincoln, 1976, 156 pages

S.J. Parnes (Ed), *"The Magic of your Mind"*, Creative Education Foundation, Inc. Buffalo, 1981, 235 pages

DESIGN INNOVATION IN SHIPPING

Current design methodologies in shipping do not stimulate and structure a systematic and holistic approach to innovation. In order to survive, shipowners have to constantly improve their performance by innovating existing services and creating new ones, which requires design innovation in shipping. In spite of the fluctuating, and often low, return on investment, shipowners but also shipyards, constantly explore new ways to do things, which either lead to improvement innovations or basic innovations.

Most of the books on design methodologies in shipping are in fact written for the naval architect, who starts his work from a rough outline specification. Hardly any book on maritime design methodology incoporates explicitly innovation in shipping as part of the design process.
In teaching students at the Faculty of Mechanical Engineering and Marine Technology of the Delft University of Technology during the past seven years, I therefore felt the need to fill in the methodological gap that exists in the domain of design innovation in shipping.

This book gives a broad overview of the many aspects of design innovation and it offers an extension of the current design methodologies. It results in a new methodology, which is called Design Innovation in Shipping (DIS).

Although the book is essentially written for a more technically oriented audience, large parts of it are also relevant for the non-technical public. The book is especially useful for shipowners, maritime consultants, shipyards and of course students at the maritime technology faculties. It may also prove relevant for financiers, classification societies, governmental organisations, students from the maritime economics faculties and the like.

ISBN 90-407-1143-7

9 789040 711435

Delft University Press
Delft Marine Technology Series