Marine traffic systems

Supplement
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Proceedings of an international symposium organized by:
Department of Naval Architecture and Maritime Studies of the
Delft University of Technology,
Liverpool Polytechnic,
The Netherlands Maritime Institute,
The Royal Institute of Navigation,
The University of Wales Institute of Science and Technology

The Hague, 11–14 April 1976

Edited by
C. C. Glansdorp

Delft University Press / 1976
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The present state of the art of port traffic management
PRESENT PORT TRAFFIC GUIDANCE SYSTEM IN THE ROTTERDAM PORT AREA AND ITS FUTURE DEVELOPMENT

G. van der Graaf*

Summary

This paper intends to give an overall view of the way in which the shipping traffic in the Rotterdam port-area and in its approaches from the sea is operated, the problems we are or we were facing and the manner in which we try to solve these problems. I hope it will be clear from this paper that in my opinion traffic guidance is not a single art or a single technology that can be worked out as a mathematical problem with a fixed number of parameters.

Introduction

Traffic guidance is the result of the measures that are taken in order to handle the flow of ships as smooth as possible. Very important is the geographical situation; i.e. a rather long fairway (15 NM) with tidal currents in which constantly a certain number of ships is going in, or going out and a focusing area off the entrance. (see figure 1).

Under normal conditions the traffic will continue at its own discretion so far regulations permit. When the weather is unfavourable the normal traffic flow is disturbed. Another reason for disturbance of the normal traffic flow is the nautical hazard; i.e. a breakdown, a collision or may be even a rogue.

It is apparent that the commercial authorities require the optimum use of their investment and their equipment; they therefore demand the maximum of the transport capability. The activities of the Rotterdam port area spread out over a wide area of possibilities and therefore the ships that call at this port vary correspondingly; from the giant tanker to the small coaster, from the ordinary well organised ship to the disabled floating object.

As a result of these factors the Rotterdam port area and its access to the sea is usually full of ships going in or out with specific peak periods at an average of 100 ships per day in each direction. With a possible exception for marginal shipping all masters want to proceed to their berth as quick as possible.

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Delay in departures have to be avoided because there may be another ship waiting already for that same berth. In the Netherlands the navigation policy is left as much as possible to the discretion of the master so long as he complies with the rules and regulations introduced by Government and Municipalities.

Traffic guidance is the result of all measures that are taken in order to handle the flow of traffic as smooth as possible, each ship considered according to its own capabilities and bearing in mind that the aim always must be the safe and expeditious arrival of the ship at its destination (and vice versa).

The traffic guidance is carried out with the aid of a radar chain, radio-telephone, line and telex communication and last but not least a proper coordination centre.

In this free democratic society we live in, it is unavoidable that more than one authority is involved or at least interested in the operation of ships in a port.

The only way to ban duplication of actions - whatever they may be - is to get together and cooperate. Thus it is necessary to gather all the information that is needed in that coordination centre.

II. The present state of the art and the way it developed.

The present state is a result of several measures that mostly were taken separately. They were based on practical experience. It will be of interest to review the different aspects that affected the development in the guidance of traffic.

I want to emphasize that up till now traffic guidance in the Rotterdam port area concerned mainly seagoing ships because:
- the radar system was in its origin designed to assist piloted ships only during bad visibility and as a result is manned by personnel that belongs to the pilot services;
- inland shipping is not present in about 50% of the area where the system operates.
- inland vessels were not as numerous and as large as they are nowadays;
- inland vessels were generally not equipped with VHF radio installations. This still goes for the majority of them;
- the pilotage authority does not have an expanding policy in the field of inland traffic guidance, since the necessity, the tools and the organizational structure for it have not been present.

The above mentioned factors which still are of importance, have caused the focusing on seagoing ships of the traffic guidance and this paper on this subject.

It may be clear that there is geographically a difference in:
1. the approach area where pilot operations are carried out;
2. the fairway from the pilot area to the inner ports;
3. the role of the radar chain and the necessary means of communication;
4. the traffic guidance.
1. The approach area.

Seaborne traffic bound for Hook of Holland converges at the pilot station because it is there that the master can expect the assistance he will need to proceed safely to his berth.

Ships are approaching from all directions between South through West to North East to this focal point.

As shipping increased (see fig. 2) the poor skipper of the pilot cutter felt himself entrapped. The closer the ships came the more difficult it became to carry out his transfer operations safely. In addition under influence of the tidal currents the whole bunch drifted away across the direction of the harbour entrance. If he tried to pull up towards a more favourable position all ships would follow him as little ducks their mother. During the hours of darkness it was difficult to distinguish the incoming ships from the outgoing ones and sometimes it occurred that the pilot, the skipper thought he had to transfer, returned with a fellow pilot who was only too happy that he finally was taken off his ship.

To avoid this sort of situation a dual pilot station was introduced when the amount of transfers had risen to appr. 800 in a fortnight.

A cutter on the Westerly cruising station embarks pilots on incoming ships; a cutter on the Easterly one disembarks pilots from outgoing ships. The cutters are separated about 3 N.miles, thus separating the incoming and outgoing traffic flows. They swap positions when appropriate.

However, as shipping still did increase, it appeared that the turn round of the pilots (at peak periods) had to be so quick, that when he was picked off his ship by the Easterly pilotcutter it took too much time to have him available at the other cruising station for the corresponding return trip. Consequently fast pilot launches were introduced. When necessary the fast launch takes him directly to his next ship. The pilot launch provides a fast means of transportation in the roadstead area.

(Together with this method of operation a new procedure of communication was introduced that will be reviewed under item 3). The masters who were acquainted with the situation at the pilot station complied with the rules and went to the correct cutter. However there still was a considerable number of captains that did not, or did not wish to comply with the regulations and sometimes the situation was really hazardous in particular when VLCC's appeared on the scene. These giant ships have to pass along a fixed track into the harbour.

There was a definite need for proper traffic separation and in 1971 two schemes were introduced. (see figure 1). One for ships approaching from the S.W. or West and one for ships coming from a Northerly direction. Both schemes were promulgated by IMCO. The MAAS-reconnaissance buoy was renamed MAAS-Center, positioned in the line of lights at 10 N.Miles out.

Ships are to pass this buoy in a counter clockwise direction. The dredged channel for VLCC's was incorporated in the schemes. The Westerly traffic separation scheme was fixed South of the VLCC channel.

Since VLCC's are not fit for stopping manoeuvres in the pilot
fig. 3
area, their pilots are transferred by helicopter (see figure 3) in a position 25 miles out at sea, where the helicopter can make Rendez-Vous away from other shipping. VLCC's thus pass through the approach area without delay, and they must keep MAAS-CENTER BUOY at their starboard side. According to the Rules of the Road this does not interfere with the incoming traffic from the North. Special anchorage areas have been introduced away from the normal traffic zones. Ships that have to wait for their berth can safely await their turn for proceeding.

Masters of ships get more and better acquainted with the separation schemes and we are confident that they will consider it a correct guidance for a safe and expedientous approach to the Hook of Holland. One should however bear in mind that a pilot station or better an area where pilotage is carried out, will remain an area where the masters must pay extra attention to the navigation.

Bad weather, poor visibility or sometimes ships that do not communicate in a proper way may cause interference with the properly designed scheme. Each situation must be considered in itself; one cannot make hard and fast rules for all cases. It is evident that ships going astray must be brought to order in the most efficient way.

The time of arrival of the ships used to be known more or less accurate and in most cases the broker had to be asked if this time meant the time of berthing or of something else. In order to increase the efficiency of the pilotage operations in the crowded roadstead it became necessary to minimize the number of unexpected ships asking for pilots. This resulted in the obligation that ships have to assure that their exact time of arrival at the pilot station has to be known there at least 4 hours prior to their arrival.

All these measures were of considerable support to handle the traffic flow more smoothly and more efficient.

The next item is to see what will happen to the seagoing ships when they proceed to the harbour.

2. The Inland fairway.

When ships are provided with a pilot or, if not, when they are reported, as a rogue that goes inward, they will set course towards the harbour entrance. Their destination may be Europort or New Waterway. They have to interweave in this area.

For Europort the situation is rather simple. More complicated is the situation for shipping going upstream to the inner ports. For the Botlek harbour area ships are admissible with a draft of 45 ft. The traffic is mainly seagoing ships and the flow is rather simple. More upstream the inland ship traffic will interact with seaborne traffic and it is unavoidable that there is cross traffic going from one harbour basin to another. The seaborne ships have a constant communication with the radar stations thus enabling them to exchange all necessary information for their navigation.

The inland barge traffic remains difficult to handle. As an average it is uncertain where they are going. However, from their course, speed and position an experienced local man (as the pilot is) can decide fairly sure how they will act and
proceed. There nevertheless should be introduced a better means of control of the inland barge traffic. Trouble spots are located just in front of the inner harbours. Barges usually are so low in the water that they hardly can be observed from a ship on the river and they appear very often at a moment that correction in manoeuvring is hardly possible.

A first step to a solution for this problem would be if the barge skipper, who intends to sail, would have to report his ship's name and his intended movements to the harbour coordination centre prior to his departure so that he is known to be there and can be ordered to act according to a prescribed plan or schedule. However, a majority of the inland vessels is not equipped with VHF radio installations, which makes such a rule, and with it adequate control of the movements of inland vessels rather illusionary. The traffic in the inner ports does not give great trouble. Seaborne shipping is usually assisted by mostly two tugs, the bigger ships even more, and they are well under control. The problem of the barge traffic remains.

In Europort area the seaborne and the inland traffic are geographically separated and there are no great problems in concern with traffic guidance since the density of shipping in this area is less than at the New Waterway. The size of the ships however plays a dominant role.

3. The radarchain and the necessary communications.

The present marine traffic system along the New Waterway, which is known as "the radarchain" since it is older than the presently used expression became fully operational in 1957. It was originally mainly intended to assure the continuation of seagoing ships traffic during periods of bad visibility. The chain consists of 8 radar stations along the river; the end station at the Hook of Holland covers the entrance area at sea up to about 20 nautical miles. In the early stage the radarsstations operated individually. They cover river sections of approximate 7000 meters which are partly overlapping. Each stations has its own frequency and when a ship proceeds from one block to the next this is reported via line communication to the operator in the neighbouring radar station. In order to guarantee a proper ship-shore communication, portable radio sets were issued to the pilots. The basic aim of this radar chain has been to give information to the master of a ship (via the pilot) to enable him to continue the navigation under unfavourable conditions.

During the early years of operation it became apparent that there was a need for overall control of these radar operations and that it was important that the radar operators would have a source of information in case of doubt. The radar centre was introduced as an interim coordination centre. Also the practice learnt that in cases of high shipping density it was difficult to give all ships proper assistance during bad visibility, due to capacity problems. Thus the need for regulation of traffic during poor visibility arrived. After a period of familiarisation the use of radar assistance increased rapidly,
growing out to a form of traffic information for the master and
the pilot on which they could plan their navigation under all
circumstances. The importance of radar assistance became evident.
The difficult positions were the entrance areas of the system
that is: When a pilot boarded a ship he called the radar
station at Hook of Holland, reported ship's information and his
position and asked for radar assistance. Because of the increase
in shipping this system did not work properly at busy hours as
a result of which errors were made sometimes. The best solution
to solve this problem was to channel all initial information in
an early stage. It became necessary to coordinate the pilot
operations and to separate this form of administrative radio
traffic from the nautical radio traffic via the radar frequencies.
The major problem of identification remained. A separate radar
scope was connected to the station of Hook of Holland with
which (using the same aerial) a surveillance area with a radius
of approximate 20 nautical miles can be supervised. Approaching
ships are obliged to report initially to this surveillance
station called "Pilot Maas" and the master is informed with
all the news he is anxious to know (i.e. berth, pilot, nautical
situation, etc.)
When necessary he is informed about the pilot cutter's position
or where he could come at anchor to await his turn.

It will be seen that there is no direct communication between
pilot cutter and ship and neither between pilot cutter and the
radar station "Hook outer". The advantage of this set up is that
all necessary radio communication in the radar frequency is
avoided and own operations are made more profitable.

When a ship is difficult to locate she is set on a specific
course to identify her track. The other end i.e. the port area,
is supplied with the ships coming out of the harbours or leaving
their berth at the riverside. It became necessary to control
the departure of the ships to assure that they can leave their
harbour basin without danger and can safely join the flow of
ships on the river. To achieve this, the exact time of departure
should therefore be timed in relation to these exogene factors.

The importance of the radar chain was greatly affected by the
availability of the portable VHF set. In 1963 all pilots
received their own set which they carried with them all the time,
even to their home. They could even charge the battery there.
The use of radar assistance grew to a round the clock service.
All piloted ships are in constant radio contact with the radar
stations and receive all information that may be needed to make
the decisions which are necessary for a safe passage through
the area. Also seagoing (and other) vessels which are equipped
with VHF installations, but have no pilot aboard, are using
the system by listening to the information given and occasionally
giving or asking information themselves. The original functioning
as an instrument to keep the seagoing traffic going during periods
of poor visibility is now only a minor part of the activities
the system is used for.
<table>
<thead>
<tr>
<th>YEARLY</th>
<th>WEEKLY</th>
<th>AVERAGE BRT PER VESSEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.000</td>
<td>750</td>
<td>7.820</td>
</tr>
<tr>
<td>37.000</td>
<td>7.25</td>
<td>7.000</td>
</tr>
<tr>
<td>36.000</td>
<td>7.00</td>
<td>6.750</td>
</tr>
<tr>
<td>35.000</td>
<td>6.50</td>
<td>6.500</td>
</tr>
<tr>
<td>34.000</td>
<td>6.25</td>
<td>6.000</td>
</tr>
<tr>
<td>33.000</td>
<td>6.00</td>
<td>5.500</td>
</tr>
</tbody>
</table>

fig. 4
4. Traffic Guidance

In brief this is the traffic guidance in its present state, carried out in the Rotterdam port area and its adjacent areas. From this paper it will be seen that traffic guidance is not a specific art or a mathematical subject. It consists of a series of measures taken when the situation requires adaptation. It added up to the growth of Rotterdam to the biggest port of the world with finally about 40,000 ships coming in to the Hook of Holland and going out again every year.

It has proved to be one of the safest ports of the world as far as navigation is concerned.

This presentation does not cover all the details that are of importance. I tried to present the general outline. The subject has been approached from the nautical and the maritime aspect. Other angles of view will be presented further in this symposium. Now I will endeavour to present some aspects of the development of a new traffic guidance system, which in due time has to replace the present one.

III. Developments concerning a new traffic guidance system.

1. Backgrounds of the chosen method.

About fifteen years ago the first steps towards a new traffic guidance system were taken, mainly because the necessity to have it replaced would arise soon and in consequence of the immense increase in number of the traffic movements which at that time made visible the limitations in the capacity of the present system. A new system was designed, based on the concept of the present system as outlined above, together with "the lessons learnt" from the experience made in the preceding period, but with a larger capacity with respect to piloted vessels. The design of this new system was completed in 1971.

Meanwhile it became clear that the economic and political situation in the Netherlands was changing. The years of economic expansion were fading. New prognoses of shipping in the years to come, learnt that the increase of the ship's size would be more than the increase of the cargo. The increase in the number of ships per year had ceased. Since 1973 the amount of shipping went down with 3% yearly. Although the BRT tonnage coming to Rotterdam was about 10% more in 1975 than in 1974, the amount of cargo did not increase. For the near future it is expected that the number of seagoing ships will not exceed the present amount. And a similar process is developing for the inland shipping.

There is an overall fear for new technical and industrial developments. The population becomes anxious because of the influence of it on the environmental circumstances. For that reason the authorities must adhere very strictly to the rules and regulations that have to guarantee the best living conditions possible. From the accidents with vehicles with dangerous goods it became more apparent that control of the traffic was
desirable. This certainly went for shipping where the story of the dangerous liquid cargo be it small or large, was rapidly accepted. When the design for a new radarchain together with its auxiliary equipment for traffic control and traffic information was introduced the Rotterdam municipality expressed a strong view to be able to control all shipping traffic. Since traffic control is—in the Netherlands—also to the interest of the service, responsible for the maintenance of the waterworks and fairways, it will be seen that there are three authorities who have interest in traffic control. The Rotterdam municipality rejected the original design for renewal of the existing radarchain because that plan did not cope with her new ideas about traffic control. A new form of cooperation was introduced between the three authorities participating in the development of a radar assisted control system for shipping. A steering group was installed and charged with the task to formulate the principles upon which the system should be based. Preliminary studies showed that first of all some principal questions had to be answered before being able to get to work on the new hardware at all. The main aim was to guarantee the maximum safety for shipping and the maximum economic advantage from the investment that should be made; this all being related to the geographical situation in the area. Some principal questions were:

- Is safety of shipping an objective in itself or is it a condition for the protection of infrastructural works?
- Is traffic control feasible?
- Can safety of shipping be increased by a traffic control system and how?
- What can traffic control achieve in relation to other instruments for increase of safety?
- Does traffic control affect the economical profits of the users of the port?
- What kind of use of the system is the most important; pilotage or traffic control?
- What are the responsibilities of the respective authorities concerned?

It has become clear that as long as questions like those mentioned above, have not been solved, it is impossible to lay down a common doctrine on traffic guidance or traffic control. We are now facing two visions:

i. start from the present situation and make use of existing rules and regulations as much as possible;

ii. try to realise the ultimate that technically can be achieved in future.

The method of policy analysis which is used by the Dutch Government was chosen to analyse the objectives of the parties interested in relation to the objectives a traffic control system can help achieve. This method is described in appendix I.
2. Preliminary results.

The first step in applying the method for the project has been to carry out an objectives analysis with the aim to produce the objectives of the new traffic guidance system. The main objectives for the system were distinguished. One concerning the safety, the other the economy of the port. The main objective concerning safety has been subdivided into an objective concerning the prevention of potential dangerous situations and one concerning the curative aspects after the occurrence of accidents. The economic main objective has been subdivided into the fields of economic demand and supply. The resulting structure of objectives is shown in figure 5.

As can be seen the role of the traffic guidance system is one of supplying and/or relaying information, enabling the authorities to activate other instruments to achieve the proposed objectives. Another important aspect is that the role of the traffic guidance system is a supplementary one. It is an instrument which is used in these policy fields next to many other instruments (tugs, linesman, patrolcraft, pilots, rules and regulations, buoyage, signals etc.) it has not yet been possible to subdivide the objective concerning the economic demand into single objectives since it is not yet known if a traffic guidance system has a positive effect on the decision of a potential user of the port whether or not to use the port of Rotterdam instead of another one.

The next step (comparing the objectives of the system with those of the parties concerned) was complicated by the lack of authorized policy objectives of all parties concerned. However, they have been able to indicate their policy fields insofar as these concern a traffic guidance system.

The municipality of Rotterdam considers a traffic guidance system to be an instrument to achieve municipal objectives concerning the health and safety of the municipal population, law and order and the economy.

The department of Public Works considers it to be an instrument to achieve objectives concerning the maintenance of the navigability of waterways, prevention of the salting up of inland waterways and the supply of water to the industry and population, the increase of capacity of waterways, their safe and appropriate use, protection against water pollution and the increase of their social profits.

The Pilotage Authority considers the traffic guidance system as an instrument to achieve objectives with respect to safety of shipping and internal objectives concerning business economy. It has not yet been possible either to establish a connection between these objectives and those to which a traffic guidance system can contribute or to make a quantification of this contribution. Furthermore some of the objectives mentioned may be classified as activities or instruments which are connected to objectives of other authorities than the ones involved in the project. The benefit of the traffic guidance system with respect to the objectives of the system itself also are difficult to establish, due to the presence of a few complicating factors.
### Figure 5 Structure of objectives of the traffic guidance system

<table>
<thead>
<tr>
<th>main-objectives</th>
<th>sub-objectives</th>
<th>single objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Contribute to safety in and around the port area</td>
<td>1.1. Contribute to the elimination of possible causes of potential unsafe situations</td>
<td>1.1.1. Foster the presence of the right information.</td>
</tr>
<tr>
<td></td>
<td>1.2. Contribute to minimizing of the effects of accidents.</td>
<td>1.1.2. Cocreational of conditions for the right use of available information.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2.2. Contribute to the limitation of the number of ships involved in occurred accidents.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2.3. Contribute to the continuation of ships traffic not involved in occurred accidents.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2.4. Co-creation of conditions for elimination of other effects of accidents.</td>
</tr>
</tbody>
</table>
2. Contribute to the continuously tuning of the possibilities for transport and distribution of the port to the developments of the traffic flow.

2.1. Contribute to the development and maintenance of the possibilities for transport and distribution of the port.

2.1.1. Contribute to the tuning of the entering of ships into the area to the availability of berths.

2.1.2. Contribute to the prompt availability of pilots.

2.1.3. Co-quarantee the smoothest possible movement of vessels within the port area.

2.2. Contribute to the desired development of the traffic flow.
The first of those is the already mentioned fact that a traffic guidance system does not exclusively guarantee safety and economy, but only contributes to it, due to the presence of many other instruments with respect to the same objectives. Setting up a traffic guidance system therefore creates overlaps in some extent with respect to already existing instruments. A second problem is the fact that due to the long period the present system has been functioning, it has become impossible to compare the levels to which the objectives can be achieved using a traffic guidance system with the situation that there would be no system at all. It is only possible to compare the results of a new system with the present situation. So only the benefits of the now non-existent parts of the new traffic guidance system, which are the extra subsystems needed for traffic control (such as a central visual presentation of the whole area and a prediction system) can be estimated. This estimation is not an easy one due to existing conditions. First of all masters have liability for the damage and effects of accidents in which their ships are involved. This liability also exists if the accident is a result of the execution of orders given by a traffic controller. The implementation of traffic control means that existing laws have to be changed in such a way that the liability of the master is transferred to the authorities in case of accidents resulting from traffic control measures. This will have a negative influence on the possible benefits of traffic control. A next problem is the already mentioned lack of VHF installations aboard ships. A traffic controller must be able to communicate with all ships in his area. Otherwise it will not be possible to give ships orders without impairing safety. This means that all the inland vessels in the area have to be equipped with VHF installations and have to be enforced to use them. If this cannot be achieved traffic control beyond the present situation is not feasible. These measures require new by-laws and otherwise high investments for shipowners. In my opinion it is doubtful if it is possible to fulfill these conditions for traffic control in the next decade. Since absolute safety cannot be achieved (technical failures and human errors cannot completely be eliminated by any traffic guidance system) and the present level of safety in the area concerned may be considered as very high already, a preliminary conclusion is that the contribution of a traffic guidance system to the increase of the present level of safety only has a limited extend. The same conclusion has to be drawn with respect to the economic objective. This mainly because shipping traffic is only a minor part of the total transportation process in the port and the authorities do not apply instruments to control the rest of this process. In short it can be said that, in the present situation, these preliminary conclusions hardly give rise to build a very advanced traffic guidance system with the purpose of making possible the implementation of traffic control. About the costs of the extra attributes of a traffic guidance system needed for traffic control, nothing is known. They are estimated to be about half the total costs of the system
(excluding costs of external provisions). The fact that the economic benefits, if they are present, mainly affect the users of the port facilities, gives rise to the question whether the shipping industry is willing to share the costs of the traffic control attributes of the traffic guidance system. It should be noted that due to an existing treaty concerning the ships traffic on the Rhine river it is not possible to have the ships "using" the system pay part of it.

The willingness of the industry to pay for part of the costs made to increase the safety of ships and their cargoes should be investigated and may create an extra dimension with respect to a cost-benefit analysis of a highly advanced traffic guidance system.

Since the policy analysis for the traffic guidance system has not yet been finished concrete information about the necessary instruments and activities and their relative importance is not yet available. Also most of the basic questions mentioned earlier (see III, I and appendix I) have (although investigations have started) not yet been answered. I hope discussions at this symposium may lead to a better understanding of those questions. However, a preliminary investigation of the existing instruments and activities has started already and gives reason to believe that the use of the method of policy analysis for this project will eventually lead to a more efficient use of instruments which are necessary to assure an optimal accessibility of the port of Rotterdam.
APPENDIX I

1. Policy analysis

A policy analysis is the systematic development, analysis and comparison of policy and/or policy projects.
It can be described as follows:
There is an (more or less) abstract policy objective.
It has to be systematically investigated if the different processes which are going on or their resulting effect are developing themselves towards this objective.
When it appears that this not so, it has to be tried to exercise such an influence on these processes that the policy objective is achieved earlier and/or better.
Exercising influence on processes is done by "instruments".
The government has many instruments at its disposal. Examples are legislation and subsidies.
Before using an instrument it has to be investigated if this instrument influences the process in such a way that it moves in the direction of the policy objective. This investigation comprises:
  a. Knowledge of the process;
  b. Knowledge of the instrument which is to be used;
  c. Analysis of the effect the instrument has on the process;
  d. Weighing the useful effects of the instrument against its ill effects.
After finishing this investigation a well grounded decision can be made about using or not using the instrument concerned.

2. The method of investigation.

Restricting to public authorities it can be said that any policy has abstractly formulated main objectives. For all separate public authorities (departments, municipalities etc.) these objectives have to be specialized into less wide ranging and less abstract lower level sub-objectives. This process is continued until one reaches the lowest level of objectives. These last objectives cannot be subdivided in a lower level of objectives and are called single-objectives. This method is called "objectives analysis".
An example of a lowest level objective is "learning the English language". A subdivision like "learning English grammar" is not possible since this is unmistakably an instrument for learning the language.
There are two methods of objectives analysis.
A. The deductive method.
Using this method the single objectives are logically derived from the abstract main objective(s). This method is a judging one, it is directed at the future and shows what should be the desirable policy. For this reason this method is a.o. used for determining political policies.
Programblocks

Programs

Program-elements

Instrument-activities

111 single objective
111.1 .. ..
111.2 .. ..
111.3 .. ..

112 single objective
112.1 .. ..

113 single objective
113.1 .. ..
113.2 .. ..

1 main objective

11 sub objective

111 single objective
111.1 .. ..
111.2 .. ..
111.3 .. ..

112 single objective
112.1 .. ..

113 single objective
113.1 .. ..
113.2 .. ..

12 sub objective

121 single objective
121.1 .. ..
121.2 .. ..

2 main objective

201 single objective
201.1 .. ..
201.2 .. ..
201.3 .. ..

202 single objective
202.1 .. ..
202.2 .. ..
202.3 .. ..
202.4 .. ..

3 main objective

etc.

fig. I.1. Lay-out of a program structure
B. The inductive method.
This method starts from the activities and leads to an inventory of and insight in the current policy. This method involves the operative levels in the analysis.

A disadvantage of the deductive method is that it may lead to the formulation of objectives which in practice are not or cannot be pursued.
A disadvantage of the inductive method is that by analysing activities some objectives may be failed to observe since one activity can serve more than one objective.
To avoid these disadvantages both methods have to used in order to realise a detached structure of main - sub - and single objectives (the structure of objectives). With this structure the relations between the objectives of the different public authorities can be established.
In the case of joint projects of different authorities it is possible to work in a "horizontal structure" within which the objectives of the project are formulated and compared with the objectives of the involved public authorities.
Next the tasks of the authorities involved - as far as they are relevant to the project - are defined. In order to do this it is necessary to have a common program structure. A program structure is a combination of the above mentioned structure of objectives with the for the achievement of the single objectives necessary instruments and activities. An example of such a program structure is shown in figure I.1. The compilation of this structure requires an inventory of activities and instruments. Partly this has already been done as part of the inductive analysis of objectives. However, it is possible that not all the corresponding objectives have emerged during this inductive analysis because the operative levels often tend to see the instrument as the aim of an activity.
An example is that the construction of a marine traffic system may be seen by some people as an intermediate objective, whilst this of course can never be the ultimate aim of the policy of the public authorities. Consequently constructing marine traffic systems is an instrument.
Making inventory of the activities automatically leads to an inventory of the used instruments.
This makes it possible to bring all the activities together which are used for one instrument and thus form "program elements" which have to be coupled to the single objectives as shown in figure I.1.
The program elements are the smallest building materials of the program structure.
To obtain a good insight in the program structure the number of instruments in a program element has to be limited as much as possible, because in practice each instrument always appears to be able to serve more than one objective. In the next stage of the program analysis the instruments are tested to determine their effectiveness (of course related to the objectives). For this purpose a classed inventory is made of the corresponding activities. Besides this a quantitative relation has to be found between instruments and objectives. This means that a standard
Cost-benefit analysis of instruments, weighing of alternatives against each other
has to be found which indicates the output of the instrument as well as to which extend it serves to achieve the proposed objective. When formulating the single objectives this has to be taken into account in such a way that quantifying becomes possible. Parallel with defining these effects the costs of the instruments can be calculated. This makes it possible to define the net effect of the instruments by a cost benefit analysis. The whole process eventually leads to the answer on the questions.
- Which instruments have to be chosen?
- Is it necessary to reconsider certain objectives when it appears that they - because of the costs of the necessary instruments - cannot be achieved?

In conclusion it can be said that the method of objectives analysis and the program structure can be considered an effective instrument for policy making as well as for evaluation of the effectivity of the presently pursued policy. A flow diagram of the method is shown in figure 1.2.
Management requirements of port traffic guidance systems
has to be found which indicates the success of the implement as well as the which result it serves to achieve the proposed objective; keep in mind the major objectives this has to be taken into account to assist in that quantifying factor possible. Parallel with offering those efforts the costs of the instruments can be calculated. This makes it possible to define the overall effects of the instruments by a total balance sheet.

The whole process essentially leads to the answer to the question:

- Which instruments have to be chosen?

It is necessary to consider various factors such as:

- The economic evaluation of the instruments.
- The environmental impact of the instruments.
- The social acceptance of the instruments.

In conclusion, it can be said that the economic, environmental and social instruments can be managed in an effective manner. In practice, this is subject to the estimation of the effectiveness of the procedures involved. A flow diagram of the method is shown in Figure 1.
The subject of control of marine traffic in Canadian waters had its early beginnings with the St. Lawrence Seaway Authority following the opening of the St. Lawrence Seaway in 1959. The Traffic Control System that was brought into being in those days was a rather loose type of control and involved mainly a monitoring and keeping track of the location of vessels within the area of responsibility of the St. Lawrence Seaway. This monitoring system of the Seaway Authority has, since those early days, become more sophisticated. This increased sophistication has come about as a result of increased traffic and resulting congestion at the various canals which have necessitated a much tighter control of shipping movements to speed up their transit through the system and eliminate or reduce those time-consuming situations. Improvements that have been made include a closed circuit television system which provides a continuous monitoring of shipping moving through the Welland Canal. In the further sophistication, a natural spin-off has been the increased safety of navigation involved.

From these early beginnings and right through the traffic control developments in Canada, VHF communications have been the backbone of the systems.

The next area that was given close scrutiny was the St. Lawrence River, from Montreal downstream towards the Gulf of St. Lawrence. The Department of Transport was concerned with the number of accidents occurring in the River, whether they were groundings or collisions. There were requests for some sort of traffic regulating from pilots' representatives, seamen's unions, ship operators and others. The Department concluded from the information gained during investigations of several major accidents that there was a need for the regulating of traffic and improvement in the provision of navigation safety information to ships in transit. It was decided, therefore, that a more complete picture of the traffic moving and of the forces that were being brought to bear on this traffic should be obtained through the institution of a Traffic Control System in this section of Canadian waters and so achieve greater safety and efficiency through the safe, speedy and more orderly flow of marine traffic. It was then, in 1966, that such a system was put into operation and that system, like others that have been developed since in Canada, with the exception of the St. Lawrence Seaway Authority System, is known as a vessel traffic management system - the St. Lawrence Seaway still retaining the terminology Marine Traffic Control System.

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Following the putting into operation of the St. Lawrence River System, the world was shocked by the Torrey Canyon incident in 1967, and Canada three years later by the Arrow incident. Both of these casualties resulted in massive pollution of the nearby marine and coastal environments. There were public demands that governments should take action to more closely control and manage marine traffic movements in order to significantly reduce the possibilities of future occurrences of this nature.

In 1960, the International Conference on Safety of Life at Sea (SOLAS '60) in Chapter V, "Safety of Navigation", required all ships of 1600 gross tons or more, with special exceptions to 5000 gross tons which were engaged on international voyages, to be fitted with a radio direction finder (DF). This very modest requirement was an early effort by the International Marine Conference to regulate ship borne navigating equipment.

In 1968, in response to the serious pollution caused by the stranding and loss of the s.s. "Torrey Canyon" off the southwest coast of England, the Inter-Governmental Maritime Consultative Organization (IMCO), in an extraordinary session, amended Regulation 12, Chapter V, to require ships to be fitted with a radar, gyro compass, echo sounder and to take all reasonable steps to keep this equipment in an efficient condition. With the exception of radar which is required on all ships of 1600 tons or more, the application of these provisions was limited to specific ships engaged on international voyages.

The Torrey Canyon and Arrow incidents, coupled with increasing concern by Canadians on the preservation of their marine environment, prompted the Canadian parliament to enact Part XX of the Canada Shipping Act. Part XX, which dealt with "Pollution" delegated to the Ministry of Transport wide powers to legislate requirements for all shipping in Canadian waters outside of the Arctic which was already dealt with by the Arctic Waters Prevention Pollution Act. These powers included provisions for making regulations respecting the fitting, maintenance, testing and use of electronic and other navigational equipment on ships carrying pollutants in Canadian waters.

At this same time, the Coast Guard had under review, and were proposing amendments to the Navigating Appliances Regulations. As a result, the Navigating Appliances Regulations were completely revised to introduce effective requirements for the fitting and maintenance of navigating equipment in all ships in waters under Canadian jurisdiction and go beyond the IMCO requirements, both in the amount of equipment and scope of application. These Regulations require a gyro compass, sounding apparatus, radar (two on tankers and chemical carriers), efficient internal communications systems, bridge-to-bridge radio telephone, manoeuvring system indicators, and manoeuvring and appliances data in the case of larger vessels, with manuals and spare parts being required for these appliances.

In addition, in October 1972 Canada established the charts and publications regulations which required ships to be provided with adequate charts and publications, giving effect to Regulation 20 of Chapter V of SOLAS '60.
In addition to the navigating safety package consisting of appliances, personnel, charts and publications, and practices and procedures, the Ministry has established a number of other important navigational measures, including ship routing systems. With the foregoing concerns in mind, it can be appreciated that the Ministry of Transport, in its role of ensuring the safety of life and protection of the Canadian marine environment, had to direct its attention to expanding its vessel traffic management systems into those areas of the country where the type of traffic was such as to pose a possible adverse effect on the marine environment unless it was properly monitored and managed to the highest degree possible. As a consequence, you will find on looking at a map of Canada that vessel traffic systems have been developed and put in place in a number of locations across the country, from Newfoundland through the Maritime provinces, the Great Lakes and out on the west coast. The systems that have been implemented are of varying degrees of sophistication in that we recognize that different parts of our country vary as to the degree or level required for managing or regulating marine traffic. Such things as the geography of the area, the volume and type of traffic and the frequency of accidents have an effect on determining the degree or level as well. In order to take care of the different requirements, we have developed four levels of vessel traffic management systems which we, in Canada, consider should cover all situations. These range from the lowest or least sophisticated at Level 1 to the most complex and most sophisticated of the group at Level 4.

Level 1 is a Ship-to-Ship or Bridge-to-Bridge Information System in which the ships alone participate. They transmit on designated frequencies at predetermined locations and provide specific information on their positions and intentions. All ships in the general area, operating on the same frequency, hear the information transmitted, and know what to expect when they reach or are approaching the area from which the transmission originated. This level is not monitored from a shore station or a Coast Guard Traffic Centre. One might expect to find a Level 1 system in the open water areas where a few hazards and low traffic density exist, and we also use it in the early implementation stages of VTM in any given area to allow mariners to get used to reporting information that other mariners in the same general area can use. It is usually implemented before such time as the shore-based equipment is available and installed to provide for shore involvement.

Level 2 is referred to as a Shore-to-Ship Advisory System. It requires vessels to obtain clearances from a shore station prior to entering a designated traffic management area. The clearance may be related to regulations at present in effect concerning the capability of a vessel to navigate safely without pollution risk while in Canadian waters. It includes the basic conditions
of a Level 1 system, in that there is ship-to-ship party-line information available to shipping. Additionally, the shore station will regulate the marine traffic to the extent of issuing clearances based on information provided by the vessel. Furthermore, the shore station will regularly broadcast information on marine traffic, aids to navigation, weather, and other items considered essential to the mariner.

Level 3 is a Shore-to-Ship Regulating System. This is considered the first step to a definite regulatory system. It has the features of the first two levels, but with the shore station at the VIM Centre maintaining an accurate plot of ships in the area, based on position information provided by shipping. This level can regulate traffic more closely, due to the more complete information required from the ship. The St. Lawrence River is generally considered to be of this level, with the exception of those areas where radar surveillance is available, and these isolated locations can be considered in the category of Level 4 at Montreal, Quebec, and Les Escoumins.

Level 4 is a Shore-to-Ship Control System. It is the most sophisticated of our Traffic Management Systems. By using radar, the shore centre has positive real time information on ships' movements and locations. We have the capability to identify targets more positively to the extent of advising ships of a recommended course and/or speed, if applicable, when we see that a serious situation is developing. This system depends on the thorough training of traffic regulators. Courses are being developed, with training in simulators to cover all aspects of the regulator's job.

In addition, it should be noted that our Vessel Traffic Regulators have been appointed as Pollution Prevention Officers under Part XX of the Canada Shipping Act. This appointment brings with it extensive powers to direct shipping and control their movements when risk of pollution is involved in Canadian waters.

When Vessel Traffic Management Systems have been established, the Ministry of Transport has prepared regulations covering each individual system. These regulations detail such things as the name of the system and provide definitions of those important factors requiring definitions within the regulations. They provide a summary of the type of vehicle to which the regulations apply, for example, vessels, air cushion vehicles and sea planes on the water. They define the responsibilities of the various members of the staff at a Coast Guard Traffic Centre and lay down the type of VHF radio equipment which will be carried, with the various frequencies and channels on which the vessel shall be capable of receiving and transmitting messages. These regulations also give instruction to the master, officer
in charge, or pilot of a vessel of when he must obtain clearance. These include such things as entering and leaving the Traffic Management zone, proceeding to or leaving any berth, proceeding after being stranded or involved in a collision, making an intended alteration of course in excess of a given number of degrees and for making any movement for the purpose of compass adjustment, navigational aid calibration, ship trials, diving sounding, servicing marine navigational aids, picking up, laying or maintaining submarine cables or for the purpose of any other operations that may impede marine traffic. Clearance must be obtained by any person wishing to land or take off in a seaplane. This particular section of the regulations will normally define the validity period for a clearance and should the manoeuvre not commence within that period, the clearance requires revalidation. Provision is also made requiring the master or officer in charge of a vessel that is carrying explosives, radio-active material or other dangerous goods to inform the Coast Guard Traffic Centre of the nature and quantity of such goods before he requests any clearance. These Regulations also define the size of vessel to which they apply and the advance notice required before entering or leaving the Traffic Management Zone. Much of the information that is required from the vessels has been identified to allow an assessment to be made as to whether a vessel is complying with Regulations which I have cited previously. Towards this end, the master, officer in charge or pilot of a vessel who applies for a clearance to enter a zone may be required to give the following information:

a. the name of the vessel and its call sign;
b. the position of the vessel;
c. the estimate of the time of arrival of the vessel at the zone;
d. the destination and last port of call of the vessel;
e. the draught of the vessel;
f. the description and total weight of pollutants, if any, carried on board the vessel;
g. the pilotage requirements for the vessel;
h. where applicable, any deficiency in or malfunction of the machinery or equipment of the vessel.

The master or officer in charge of a vessel is required to report to the Coast Guard Traffic Centre by the fastest means possible if his vessel suffers a malfunction or has a serious deficiency in onboard navigating equipment or is in any other difficulty. This requirement would cover such items as the following:

a. limited in its ability to manoeuvre due to mechanical malfunction or structural deficiency;
b. not equipped with an operable radar, rudder indicator, tachometer, compass or depth sounder;
c. not equipped with operable mooring winches;
d. not equipped with operable anchors and anchoring machinery;
e. leaking any oil or other pollutant substance;
f. in a damaged condition which may result in the release of any oil or pollutant substance;
g. not in receipt by radio, or otherwise, of all current Canadian Notices to Shipping respecting the VTM zone;
h. not equipped with the charts and publications required by the Charts and Publications Regulations;
i. listed to an angle in excess of five degrees.

Normally, in Canadian Vessel Traffic Management Systems a number of calling-in points have been designated which require the transmissions of a radio message. The master, officer in charge or pilot of the vessel is required on arrival at each of these calling-in points to transmit to the Coast Guard Traffic Centres:

a. the name of the vessel;
b. the location of the vessel;
c. the estimated time of arrival at the next calling-in point;
d. any adverse weather or poor visibility conditions.

The Regulations provide that no vessel shall be anchored in any area other than that assigned by the Marine Traffic Regulator and that a vessel at a berth shall not immobilize its main propulsion or machinery, electrical generator or on-board navigational equipment without first advising the Marine Traffic Regulator.

They may also provide for the Traffic Centre to be made aware of such things as manoeuvring restrictions due to dimensions, draught or, where applicable, its length of tow, that a vessel is apparently in difficulty or has been involved in a shipping casualty, that it has become an obstruction, dangerous to navigation, that a navigational buoy or aid to navigation is malfunctioning, damaged, missing or incorrectly located, that pollution of the waters has occurred, or that any other danger to navigation exists.

These Regulations, as adopted, provide that every person who contravenes any of the provisions is guilty of an offence and liable to a fine.

Our Coast Guard Traffic Centres routinely broadcast by VHF radiotelephone, navigation safety information, notices to shipping, weather forecasts, traffic information and, when applicable, ice and icebreaker assistance information. In addition, an important function of some Traffic Centres is the continuous monitoring of marine aids to ensure they are functioning normally and in some cases radar position verification of the floating aids is carried out also.

As I mentioned earlier in my comments, the Canadian Coast Guard has put together comprehensive regulations covering each individual system as it was developed. We are now working on the development of national Coast Guard Traffic Regulations. When these Regulations have been prepared and approved, it is intended that with the enactment of the national regulations the existing local regulations will be rescinded and rewritten to be incorporated as schedules to the national regulations.
The local schedules will enunciate the geographical limits of the specific systems and operational requirements or procedures peculiar to them. During the development there will be close consultation with the marine industry to obtain the views and provide for their input. It is our view that the national regulations will simplify the Canadian system of traffic control for the mariner and eliminate any possible confusion in the use of those systems already in place or those which will be developed in the future. Coupled with this is the preparation and production of a user's manual to provide an easy-to-understand description of the total Canadian VTM system and its requirements.

I would not want to leave the idea in anyone's mind that we are trying to impede shipping or make its progress more difficult. We are here to serve it, provide it with as much information as possible and assist it safely and quickly towards its destination.
In developing the material for this paper, the writer was advised that the word "Management Requirements" were to be interpreted to mean "what the shipowner would like" and further, "Traffic Guidance Systems" should be construed as not only the recent developments in VTS programs in the United States but also the development of routing systems (traffic lanes), aids to navigation, dredging and channel improvement work, pilotage advances and hydrographic surveying practice.

The general subject matter is of interest to the writer because it involves an area of interest where happily the owners' desires in several instances are apt to be very nearly, if not exactly, the same as those of the professional seaman. Having spent about twenty years at sea, half of them as master, I find myself, while presently and for the last eight years in shoreside management, unable to submerge completely my past attitudes and concerns about the subject under consideration.

First I will consider VTS as an area of interest as it has received much publicity recently as a sort of panacea for the myriad problems brought to the public's awareness by the great concentration of attention on the problem of pollution of the seas and waterways of the world.

What does management, and in this case it is the owner and his representative on the vessel -- the master, want VTS to do and not to do?

Management wants VTS to improve the safety of the vessel movement in confined or congested waterways without reducing the present level of vessel activity. We do not accept the premise that the only way to reduce the casualty rate is to reduce the number of vessel movements.

Management wants VTS to have all weather capability so that the systems are as effective in foul weather as they are in fair weather. With the ever increasing operating expense of vessels, both old and new, and the tremendous capital costs of today's replacement tonnage, the owner's salvation lies in improved utilization of his assets. The vessels must move and the VTS activities in our various ports and waterways must be geared to that primary requirement. Contrary to the belief of some less well informed individuals, the owner's requirement that his vessels not be delayed is not an indication of recklessness or base disregard for life and property. Human resources are every bit as critical as the more and more highly specialized vessels of this age. Witness the millions of dollars spent annually by the owners to fund union
sponsored schools charged with the task of educating our officers and seamen to handle the larger, faster, more technologically oriented vessels of our time.

In various plenary sessions in which I have participated either as a member or as observer, dealing with development of VTS for the Port of New York, two gnawing doubts concerning what was to develop seemed to pervade the thinking of many, if not most of the 'industry' representatives. First was the concern that control of the vessel would be snatched from the hands of the master and the second was that the 'system' to be brought forth would be a monster that would require additional communicators on board ship. Thus, we come to the final basic requirements of the VTS as conceived by management; it must be uncomplicated, as nearly standardized as is possible, and it must retain the master as the central decision maker.

I do not mean to imply that system designed to satisfy the needs of the Port of San Francisco should arbitrarily be applied to the Port of New York, or any other area, in the name of standardization. A Positive effort should, however, be made to utilize standard terminology in communication procedures and in establishing the organization structure to handle VTS in each locale.

The lane concept

Development of traffic systems, by which we mean the implementation of the lane concept in areas of congestion, has generally been favorably received by owners and masters of vessels in spite of the fact that 'the surface has only been scratched' so to speak. The writer has encountered and adhered to lane areas at several United States ports and in the Strait of Gibraltar. The only area encountered where absolute reliance seemed to be placed in the 'system' was during a brief experience with the lane concept on one voyage through the Great Lakes. This was no doubt a special case in that voice communication was excellent, and for the most part vessel positioning was capable of a very high degree of accuracy.

These last two conditions are more than likely to be the present major drawbacks to a more general optimization of the benefits to be obtained from the use of the lane concept. To a slightly lesser extent, I would have to mention an apparent lack of ability or willingness on the part of local authority to police the lane system as an additional reason for the concept's having failed to reach full potential.

It is my belief that the above mentioned drawbacks notwithstanding, the lane concept should be fostered and encouraged and supported by owners at this time. The technology for improvement of communications and positioning already exist and will become more and more a part of normal vessel operations in the future as owners find that they are able to justify the expense of equipment that may now be considered, in some cases, unnecessary gimmickry. Development is this area of the utilization of improved technology rarely is as rapid as the promoters of such
equipment would wish. We all know, however, that this is normally an extremely conservative industry insofar as implementation of change is concerned and that position is not without merit. However, we all recognize that in spite of the apparent snail\'s pace of the industry in making use of improved technology, the fact is that the last twenty years have revealed tremendous improvements and advances in the use of technology on board ship. We confidently expect this trend to continue and see the potential for great improvement in the safety of navigation through continued development and improvement of the traffic lane concept.

Hydrographic surveying practice

In this area, one major complaint of the owner is the delay which is often experienced between the time that an area is surveyed and the time when the conditions found appear on a chart or receive adequate dissemination to insure that all mariners have an opportunity to learn of the changed conditions. Concentration of effort in the area of survey work should be directed to those portions of the world where earthquake activity is liable to cause alterations in the contour of the seabed and to areas of heavy traffic density. These areas are fairly well established and, of course, priority should be directed to areas where casualties, should they occur, would be most catastrophic. World trade patterns are subject to change and some provision, within the present system or structure for the conduct of hydrographic survey work, should be provided to insure that proposed routes are examined in detail prior to the introduction of commercial service. As vessel configurations change, particularly in the trend towards greater vessel drafts, areas previously considered free of dangers require resurvey to insure that bottoms contours are adequately examined. I would like to propose that the resource of commercial vessels themselves be utilized to a greater extent than is presently the case in obtaining hydrographic data. As more and more vessels are equipped with sophisticated position finding equipment, it would seem to make sense for the government to provide high quality echo sounding gear that could be installed on selected commercial vessels, thus obtaining much greater coverage of normal trade routes and in turn permitting specialized surveying vessels to concentrate on areas where trade routes are expected to develop and in other areas where data may be rather sparse. The objective should be development of automatic recording equipment for the various types of data which may be desired. I believe that most owners would happily agree to cooperate by providing the \'platform\' for the developed equipment.
Dredging and channel improvement

In the area of dredging and channel improvement work, the major problem which the owner feels requires immediate attention is the unacceptable length of time that it takes to get work done. It is our understanding that in today's world the Corps of Engineers estimate that from the initiation of a project request through the completion of dredging work that anywhere from ten to thirteen years may elapse and this situation, of course, we all recognize as intolerable. Some portion of this problem is undoubtedly the result of the Corps' funding requests made to the Congress annually and for which advanced planning is most difficult. A completely revised funding procedure seems to be worth serious study.

Another problem which must be faced up to the area of dredging and channel improvement work is the question of overcoming the objections of environmentalists. We are all now painfully aware of the delay possibilities in the court established procedures for hearings, appeals, re-hearings and the like when objections to a project are raised by groups purporting to represent concerned citizens. Some action must taken that will protect the rights of all concerned and which will provide for more speedy resolution of disputes regarding potential or imagined damage to the environment. Was not the situation so charged with the potential for disaster through economic stagnation, it might almost be termed ludicrous.

We cannot intelligently restrict increases in the size of vessels, yet it is absurd to consider that an owner can put a vessel into service today and face the possibility of very nearly half the vessel's normal useful economic life expiring before a channel improvement can be accomplished, which the vessel might require. I submit to you in this area of providing adequate waterways upon which to move the commerce of this nation, we face a severe challenge to our ingenuity and resourcefulness in educating the public to the needs of the nation as a whole. Unfortunately, it would appear from the developments in recent years that the public is unaware of the value to the general population of the waterborne transportation industry. This situation must be corrected as the first step in the process of educating the public to a proper understanding of the necessity to 'trade off', in a reasonable manner, some degradation of the environment for the ultimate well-being of the nation's economy.

It is possible that the entire handling of the matter of reversing the trend towards ultimate total destruction of our environment, so as to allow the forces of nature to exert healing influence and permit natural restoration of damaged components of our environment, has been very poorly managed from the outset. Perhaps it was honestly believed that the public had to be shocked into an exaggerated recognition of the problem before our legislators dared to act to pass the laws thought necessary to correct our problems. Certainly it is doubtful whether the economic impact of what was considered necessary in the area of legislation and regulation received complete study and
evaluation. The public has had to pay and pay dearly for what might be termed crash programs when some serious doubt existed and still exists as to whether such draconian measures, as were selected, were in fact necessary. It would be an extremely interesting study to investigate whether improvement in water quality, to use one example, in a particular area was the result of the effect of spill containment hardware or whether improved operating practices, resulting in fewer spills, had contributed the greater share to the improved conditions observed. Possibly the determination may be outside of our capability to accurately identify in all cases, but the results of such an investigation could have a distinct bearing on our attitudes towards the optimum manner in which to seek corrective action for specific areas of concern.

We in the United States are prone to look for immediate solutions to most problems, usually by trying to overwhelm the problem with vast outpourings of money. Of late, in several critical areas of endeavor, there seems to be a gradually growing awareness that there may be a better way to solve problems than through the indiscriminate casting about of dollars. There may also well be an increasing willingness on the part of the public to recognize that some problems are perhaps better attacked in piecemeal fashion, so as to avoid the shock of finding that the cure is worse than the illness when massive 'corrective' doses are applied. If these readings of public attitudes have any validity, the course for this industry is clear. We must exert ourselves as never before to insure that our influence is felt in the critical areas of problem definition, identification and selection of available options, and recommendation for corrective action.

Aids to navigation

One of the primary difficulties in vessel navigation in congested waters during periods of low visibility is the inability of the vessel to positively identify aids to navigation which may appear on a radar screen and be invisible to the naked eye. We believe that adequate technology exists to insure that the identification of individual aids can be shown on a radar screen and we believe further that shipowners would be willing to bear the expense of modification of their existing equipment, even replacement of their existing equipment with standardized radars which would provide the identification capability. We believe further that considerable improvement remains to be made in the area of insuring greater reliability in fixed and floating aids to navigation. Lights of great intensity are available, power sources can and must be developed which will make the use of improved aids economically feasible.
Pilotage advances

Most owners have little direct contact with the pilot services that are offered throughout the world. Generally, problems that are encountered fall into two major areas, one of which is language difficulty, the second and equally important is the problem of unfamiliarity with the vessel on the part of the pilot assigned to handle the ship. In very few instances is the owner or his representative - the master - permitted to designate the pilot whom he wishes to handle the vessel. Some recent movement on the part of the USCG has been directed towards insuring that an understanding exists between the master and the pilot prior to the pilot's taking over the con. We think that this is a move in the right direction but that it does not go far enough.

Shipowners with large, extremely expensive vessels would be very likely to spend considerable sums of money to acquaint pilots with the characteristics and handling capabilities of their ships if they had some guarantee that the pilot or pilots so trained would be the men to handle their vessels. We believe that this practice should be encouraged through cooperation by pilot associations and similar organizations who should recognize that the desire of the shipowner to protect his vessel is not an attempt to discriminate against inexperienced pilots whom we all understand must work if they are to gain experience. The plain fact of the matter is that today the stakes are simply too high to allow young inexperienced pilots, or for that matter, old inexperienced pilots, to chance a casualty with the extremely expensive consequences that can ensue, particularly in the area of environmental damage.

Further to the area of pilotage, it is my conviction that pilotage is required in many areas of the world where it is not truly needed. More pilotage in various portions of the world should be made optional on the part of the master who may wish to handle his own vessel. This topic has the potential for extremely explosive consequences if the matter is not handled intelligently. We do not propose that a master unfamiliar with a particular area should be permitted to endanger not only his vessel but others that may be in the vicinity by failing to take or make use of the available expertise or local pilot associations. There are, however, numerous areas in the world where pilots are routinely taken simply because it is traditional to do so. This is expensive, wasteful and does nothing to enhance the professional pride or technical expertise of the vessel master. Many masters are woefully deficient in their ability as ship handlers. This is understandable because most of them seldom have an opportunity to handle their own vessel and gain the experience which such work offers. Changing the rules for pilotage where they are found to be unduly restrictive would improve the professionalism of the men who command ships and ultimately the safety of the men on board. Too often when we learn the details of vessel casualties in situations where a pilot was aboard we find that the master delayed, until it was too late, giving orders he really believed were necessary on the assumption that the pilot was the one more 'qualified' to handle the vessel.
Preparation of a paper of this nature is an interesting exercise that perhaps more of us ought to attempt from time to time. At the very least, it forces one to attempt an examination of specific problem areas where attention may profitably be directed. Hopefully also, efforts of this nature serve to stimulate the kinds of dialogue among regulatory agencies, the public, labor and industry that can clarify the needs and goals of all those charged with fostering the healthy development of this vital industry.
Abstract

This paper presents a view of a vessel traffic system in a portion of the St. Lawrence - Great Lakes Waterway, consisting of the St. Lawrence River, the Great Lakes, and connecting channels which form a 2,342 mile (3260 KM) seacoast from the Atlantic Ocean to the heart of the North American continent. Emphasis will be on international management, sector control, VHF calling and working frequencies, legal justification of special frequency allocation by the Federal Communications Commission and its application in a current active vessel traffic control system.

The paper will deal with a working vessel traffic control system- its growth, management, current status and future technology.

Introduction

This paper is a presentation of the Saint Lawrence Seaway Development Corporation's vessel traffic management requirements, their evolution, growth, management, current status and potential. This system is operated in a portion of the 2,342-mile St. Lawrence Seaway.

Background

The Saint Lawrence Seaway Development Corporation, an operating administration of the United States Department of Transportation, together with the St. Lawrence Seaway Authority of Canada, jointly regulate and control, for the purposes of commercial navigation, a safe and efficient waterway system from Montreal, Quebec on the St. Lawrence River to Long Point on Lake Erie, some 500 miles. One might logically ask: What is so unique about all this? Simply stated, these agencies are responsible for the commercial use of this portion of the St. Lawrence Seaway and in carrying out this responsibility, have worked in what is believed to be a most harmonious manner in constructing, maintaining and developing this most important waterway. The St. Lawrence Seaway has seen continued growth from its deep

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Massena, New York
draft inception in 1959 during which year some 20 million tons passed through the system to more recent years during which there have been in excess of 50 million tons per navigation season. At this point, it might be interesting to note that the navigational season has also grown to approximately nine months in length in 1975.

Management

The management of the United States portion of the Montreal to Lake Erie section of the St. Lawrence Seaway is under the direct control of the Saint Lawrence Seaway Development Corporation, a wholly-owned government corporation created in 1954 by Public Law 358. Under this statute, the Corporation was given the authority to construct, operate, maintain and develop, in conjunction with the St. Lawrence Seaway Authority of Canada, a deep draft waterway from Montreal to Lake Erie. The Administrator and the President of the Corporation and the Authority, respectively, initially appointed committees for the purpose of formulating certain rules and regulations for the operation of the waterway and in so doing, incorporate the views of the shipping industry. Subsequently, these rules and regulations were promulgated by the Corporation and the Authority and are now commonly known as the Seaway Regulations and are published in a handbook. These regulations are reviewed annually and amended as the needs of the waterway and the people who use it change.

As the St. Lawrence Seaway is a joint venture, it is operated by the two entities through close coordination of their activities. Because the shipping channel in the upper St. Lawrence River crosses the international boundary over 40 times, a vessel traffic management system which changed with each crossing would be, at the very least, cumbersome and inefficient. Therefore, the two entities agreed to apportion the 400-mile St. Lawrence section of the Seaway into five vessel traffic control sectors, two of which are United States controlled. The sector locations and the centers which control them as follows: (Fig. 1)

Sector 1, controlled from the Canadian St. Lambert Traffic Control Center, extends from Montreal Harbor to Mid-Lake St. Francis.

Sector 2, controlled from the United States Eisenhower Vessel Traffic Control Center, extends from Mid-Lake St. Francis to Bradford Point in Lake St. Lawrence.

Sector 3, controlled from St. Lambert Traffic Control Center, is called Iroquois Vessel Traffic Control and extends from Bradford Point to Whaleback Shoal.

Sector 4, controlled from the Eisenhower Vessel Traffic Control Center, is called Clayton Control and Sodus Control and extends from Whaleback Shoal to Mid-Lake Ontario.

Sector 5, controlled from the Canadian St. Catherines Control Center, extends from Mid-Lake Ontario to Long Point in Lake Erie.
Fig. 1 St. LAWRENCE-GREAT LAKES - Present Traffic Control Sectors
Manpower

The Corporation's Eisenhower Vessel Traffic Control Center is the common location for control of both Sectors 2 and 4. This Center is operated by four teams, each team consisting of a Vessel Traffic Control Supervisor, a Vessel Traffic Controller and a Vessel Traffic Assistant. These personnel perform their duties on a 3-shift, 24 hour-a-day schedule during the navigation period.

Equipment

Some of the equipment which is utilized at the Vessel Traffic Control Center is as follows:

A.M. and V.H.F. Radio (Fig. 2)
At its inception, the Corporation's vessel traffic management system operated with A.M. as the primary frequency, 2182 kHz and 2003 kHz. This procedure proved to be less than satisfactory due to excessive transmission interference from small craft as well as larger vessels within a distance of 1600 miles. Additionally, radio transmission with vessels was terminated by electrical storms thereby rendering the traffic management system ineffective. Obviously, in order to ensure the safest possible conditions for vessel transit, a constant means of assisting vessels through narrow channels and adverse currents must be utilized. To this end, the Seaway entities proposed, in 1960, the establishment of a mandatory V.H.F. communications systems utilizing radio frequencies 156.6 kHz, 156.7 kHz, and 156.8 kHz to be operational within two years. This V.H.F. communications system was one of the first such systems functioning in the world.

Between 1962 en 1967, operations were conducted on the three frequencies mentioned above. The Corporation's Vessel Traffic Control Center operated on frequency 156.8 kHz, Channel 16, as a distress, safety and calling frequency, with all calls to and from a shore station being initiated on this frequency. Channel 12, 156.6 kHz, was then used as a working frequency.

The Federal Communications Commission requirement that all vessels stand by on Channel 16, coupled with the Corporation's requirement to utilize Channel 12 as a working frequency, contributed to an overabundance of transmission on Channel 16. Therefore, to alleviate that condition, the Corporation petitioned the F.C.C. for a waiver of the requirement that all vessels stand by on Channel 16, the safety and calling frequency. The waiver was granted with the provision that the Vessel Traffic Controller would monitor Channel 16 and be responsible for keeping vessel masters or pilots informed as to these transmissions. As a result, one channel only needed monitoring by the vessel master or pilot while in the United States sectors. (Attached Appendix A
Fig. 2  ST-LAWRENCE-GREAT LAKES - Traffic Control VHF Radio & Radar Sections
is the section of Seaway Regulations pertaining to Radio Communication.)

Closed circuit television

Another means of enhancing safety and expediting vessel transits of the locks and canals is closed circuit television. This equipment is used to observe the approach of vessels to all locks, thereby enabling the Vessel Traffic Controller to efficiently direct the vessels' movements as required.

Video and magnetic tape recording

An adjunct to the closed circuit television equipment is a video tape capability which allows the replay of an accident or incident in the lock area. This is a valuable aid in determining the cause of an accident and may also assist in performing an orderly vessel inspection. Additionally, all radio communications are recorded on magnetic tape on six channels simultaneously. These valuable records are retained for periods up to one year for reference purposes.

Lock Status Board

As we obtained more operational experience, it became apparent that canalling and locking could be delayed by the fact that the Vessel Traffic Controller was unaware of the operation of the equipment at the lock structures. He did not know whether the water in the lock chamber was up or down. He did not know whether the lock gates were open or closed or the status of the fender booms. In retrospect, there can be little doubt that it is very important for the Vessel Traffic Controller to know the status of his equipment in order that there can be efficient scheduling of vessel moorings or approaches and entries into locks, etc. By the use of the lock status boards, improved scheduling was achieved.

Masters and Pilots

At its beginning, the Seaway's vessel traffic management system was skeptically viewed by masters and pilots alike. Their concern, naturally, centered on the control of their vessels. As you may appreciate, they were most concerned as to whether they would retain that control or would it be usurped by the entities controlling the traffic? This concern was resolved within a short time when the benefits of the vessel traffic management system became obvious. Although control of the vessel remains with the master and/or pilot, the Vessel Traffic Controller
gives specific instructions on such matters as when to go to
anchor, when to tie up, perhaps to slow the vessel's speed, etc.
Certain information such as traffic density, weather conditions,
etc. is simultaneously communicated by the Vessel Traffic
Controller to all vessels within a sector. Specifically, an
example of this communication might be with a vessel in proximity
to a hazardous bend. This vessel will make a security call to
the Vessel Traffic Controller on the working frequency. The
Vessel Controller then communicates on the calling frequency
with all vessels in the sector, advising of the original vessel's
location and status, thereby enabling each vessel master or
pilot to judge maneuvers and speed accordingly.
Other examples of information communicated between vessel masters
and/or pilots and Vessel Traffic Controllers are (a) estimated
time of arrival (ETA) at Calling-in-Points (see Fig. 3);
(b) traffic within the sector-meeting, passing and anchored;
(c) weather advisories; (d) pilot orders; and (e) emergency
information as a result of an accident.
The following will expand upon these examples.

a. The very unique Calling-in-Point (C.I.P.) requirements (see
Appendix B) for vessels within the St. Lawrence River-
Great Lakes System were developed for several reasons.
First, in order to schedule traffic through a canal,
it is necessary to know the location of vessels and their
ETA at the next C.I.P. Secondly, on calling and working
frequencies, the master or pilot reports to the Vessel
Traffic Controller as the vessel leaves the sector and
then reports to the Vessel Traffic Controller in the
sector he is entering, giving the ETA at the next C.I.P.
or other designated location. When a master's or pilot's
report at a C.I.P. is more than 30 minutes late, the
Vessel Traffic Controller will conduct a radio search.
If there is no response from the tardy vessel, a search by
personnel of passing vessels is requested. It is possible
that such a vessel may be aground, stranded and/or foundering
due to equipment malfunction, resulting in loss of power
and subsequent loss of radio communication. A vessel in
this condition could block the channel, restrict passage,
etc. (Appendix B)

b. Pertinent information as required by the Calling-in-Table
is relayed by the vessel master or pilot to the Vessel
Traffic Controller. This information consists of draft,
cargo, destination, pilot requirements, etc. Additionally,
young changes to the vessel's characteristics as a result of
an accident since its last Seaway transit must be reported
in order to alert lock personnel to a potential hazard such
as ship listing or poor power. The Vessel Traffic Controller
then advises the vessel of its position in relation to
other vessels and establishes its turn for locking through.

c. Weather advisories are given at least four times daily
and more often as necessary. A Vessel Traffic Controller
will give information at any time a master and/or pilot
Fig. 3 ST. LAWRENCE—GREAT LAKES - Traffic Control Vessel Reporting Points.
requests it.

d. There are designated waters in which pilotage is compulsory, with both Canadian and American pilots available for service. When a vessel leaves Canadian waters and enters American waters, a change of pilot takes place. The pilot, in conjunction with the Vessel Traffic Controller, will jointly establish the ETA at the change point (Fig. 4). Should congested traffic or an incident cause the ship to miss ETA, the updated ETA must be given to the Vessel Traffic Controller.

e. One of the most important aspects of the Vessel Traffic Control Center is evident when an emergency situation arises due to a vessel malfunction, a grounding, collision, or any incident which creates a major change in scheduling, such as stopping all traffic, closing a canal or lock facility. For example, an oil tanker may go aground rupturing tanks and spilling 300,000 gallons of crude oil. Vessel Traffic Controller must stop upbound and downbound traffic within the sector (20 to 30 ships), ascertain vessel safety, alert the proper authorities, determine the requirements for eliminating pollution, etc. It should be pointed out that radio transmission becomes extremely heavy with damaged vessel requiring assistance, other vessels requiring instructions, and shoreside crews preparing for the necessary pollution clean-up.

Communication system

Our teletype system ties all Canadian and United States locks together in the Montreal to Lake Erie section of the St. Lawrence Seaway. The principal use of this system is as a means of reporting the vessel situation at all times. Ship cargo is likewise reported, and should it be determined to be dangerous or hazardous cargo, the teletype report would be used in determining the vessel's schedule for transiting the locks. Additionally, vessel drafts are reported in order to determine any changes during transit.

Marine enforcement team

One of the Corporation's responsibilities is the enforcement of its regulations and for this reason, a marine enforcement team is utilized to obtain compliance with the regulations pertaining to vessel speed. Vessel speed limits have been established according to identified areas (see Appendix C) and doppler radar checks are made periodically in these areas. If a vessel is found to be traveling overspeed, a member of the
Fig. 4 ST. LAWRENCE-GREAT LAKES - Pilotage Responsibility
team contacts the vessel master or pilot by radio to notify him that the vessel has been observed traveling at a violative speed.

Future technology

We are looking at future technology which will assist us in the management of vessel traffic in the St. Lawrence River-Great Lakes System. Among the concepts being looked at is an Integrated Management Traffic Information Control (IMTIC), which, with the assistance of a mini-computer, would eventually make available the capability for a data message file, traffic planning and an automatic vessel location information system. Furthermore, in order to eliminate queuing of vessels at any given point in the waterway, it is necessary to project traffic throughout the system, and by simulation in fast time, identify precisely where the bottleneck will be. We can thereby better judge the method by which we might move the ships at the various locks and in the canals.

All weather navigation system

The St. Lawrence Seaway is in need of an improved all weather aid to navigation system so that ship delays due to fog, rain, snow, ice and lack of aids to navigation in spring and fall would be eliminated. One such system is Precise Radar Aid to Navigation System (PRANS), which utilizes a dedicated radar in the 9300 to 9500 kHz or X-Band. The shipboard unit would have a small computer with a digital display allowing one to read distance right or left of center line ± 10 feet, distance to the next turn, and speed over the bottom. This information would be matched to the charts for the area which the vessel is transiting thereby assisting the master or pilot with navigation of his vessel. A Precise Aid to Navigation System would enhance season extension in the waterway when the navigation aids are removed for winter or prior to commissioning in the spring.

Conclusion

Our V.H.F. radio coverage is truly the backbone of a smooth and orderly operation. However, with the advent of cheaper V.H.F. radio sets, more and more small craft are beginning to impact on air time. It should be strongly recommended that the V.H.F. working and calling frequency be safeguarded for
commercial users.

Here in the St. Lawrence Seaway-Great Lakes System, the masters and pilots know full well their position of responsibility, and we as a service organization work harmoniously with them to effect an efficient, orderly and expedient transit. Although this paper dealt with only a portion of a very complex internationally operated waterway, it is hoped that an insight was gained into the Corporation's activities in the vessel traffic management area.
APPENDIX A

Radio Communication
Listening Watch and Notice of Arrival

60. (1) Vessels shall be on radio listening watch on the applicable assigned frequency while within a Seaway traffic control sector as shown on the General Seaway Plan and shall give notice of arrival in the manner prescribed in section 64 upon reaching any designated calling in point.

(2) Notice of arrival be deemed to have been given when it is acknowledged by a Seaway station.

Assigned frequencies

61. The Seaway stations operate on the following assigned VHF frequencies:

- 156.8 MHz (channel 16) - Distress and calling
- 156.7 MHz (channel 14) - Working (Canadian Stations other than Lakes Ontario and Erie)
- 156.65 MHz (channel 13) - Working (U.S. Stations, Lake Ontario and Sector 4 of the River)
- 156.6 MHz (channel 12) - Working (U.S. Stations other than Lake Ontario and Sector 4 of the River)
- 156.55 MHz (channel 11) - Working (Canadian Stations, Sector 3, Lake Ontario and Lake Erie)

Seaway Stations

62. The Seaway stations are located as follows:

- VDX20 (Seaway Beauharnois)-Upper Beauharnois Lock-Traffic Control Sector No. 1
- KEF (Seaway Eisenhower)-Eisenhower Lock-Traffic Control Sector no. 2
- VDX21 (Seaway Iroquois)-Iroquois Lock-Traffic Control Sector no. 3
- WAG (Seaway Clayton)-Clayton, N.Y.-Traffic Control Sector no. 4
- WAG (Seaway Sodus)-Sodus, N.Y.-Traffic Control Sector no. 4
- VDX72(Seaway Oshawa)-Oshawa, Ontario-Traffic Control Sector no. 5
- VDX22(Seaway Welland)-St. Catharines, Ontario-Traffic Control Sector no. 6
- VDX68(Seaway Long Point)-Port Colborne, Ontario-Traffic Control Sector no. 7
- VDX23(Seaway Sault)-Sault Ste. Marie, Ontario-Traffic Control Sector no. 8
Radio Procedure

63. Every vessel shall use the channels of communication in each control sector as listed in the table to this section.

<table>
<thead>
<tr>
<th>Station</th>
<th>Control sector number</th>
<th>Sector Limits</th>
<th>Call in Work</th>
<th>Listening Watch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seaway</td>
<td>1</td>
<td>C.I.P.No.2 to C.I.P.No.6-7</td>
<td>Ch.14</td>
<td>Ch.14</td>
</tr>
<tr>
<td>Beauharnois</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seaway</td>
<td>2</td>
<td>C.I.P.No.6-7 to C.I.P.No.10-11</td>
<td>Ch.12</td>
<td>Ch.12</td>
</tr>
<tr>
<td>Eisenhower</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seaway</td>
<td>3</td>
<td>C.I.P.No.10-11 to Whaleback Shoal</td>
<td>Ch.11</td>
<td>Ch.11</td>
</tr>
<tr>
<td>Iroquois</td>
<td></td>
<td>Whaleback Shoal to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seaway</td>
<td>4</td>
<td>Cape Vincent</td>
<td>Ch.13</td>
<td>Ch.13</td>
</tr>
<tr>
<td>Clayton</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seaway</td>
<td>4</td>
<td>Mid Lake Ontario</td>
<td>Ch.13</td>
<td>Ch.13</td>
</tr>
<tr>
<td>Sodus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seaway</td>
<td>5</td>
<td>Mid Lake Ontario to C.I.P.No.15</td>
<td>Ch.11</td>
<td>Ch.11</td>
</tr>
<tr>
<td>Oshawa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seaway</td>
<td>6</td>
<td>C.I.P.No.15 to C.I.P.No.16</td>
<td>Ch.14</td>
<td>Ch.14</td>
</tr>
<tr>
<td>Welland</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seaway</td>
<td>7</td>
<td>C.I.P.No.16 to Long Point</td>
<td>Ch.11</td>
<td>Ch.11</td>
</tr>
<tr>
<td>Long Point</td>
<td></td>
<td>Long Point</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seaway</td>
<td>8</td>
<td>C.I.P.No.17 to C.I.P.No.18</td>
<td>Ch.14</td>
<td>Ch.14</td>
</tr>
<tr>
<td>Sault</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calling in

64. (1) Every vessel, intending to transit or in transit, shall report on the assigned frequency to the designated Seaway station when opposite any calling in point or checkpoint (indicated on the General Seaway Plan) and, when reporting, shall give the information indicated in Schedule III.

(2) Changes in information provided under subsection (1) shall be reported to the appropriate Seaway station.

(3) A downbound vessel in St. Lambert Lock shall, before communicating with Montreal Marine Control, switch to channel 10 (156.5 MHz) for a Montreal Harbour situation report.

(4) After obtaining the situation report referred to in subsection (3), the downbound vessel shall return to guarding channel 14 (156.7 MHz) and remain on that channel until it is clear of St. Lambert Lock chamber.
(5) When the downbound vessel has cleared the downstream end of the lower approach wall of St. Lambert Lock, the master or pilot of the vessel shall call "Seaway Beauharnois" and request permission to switch to channel 10 (156.5 MHz).

(6) Seaway Beauharnois shall grant the permission requested pursuant to subsection (5) and advise the downbound vessel of any upbound traffic that may be cleared for Seaway entry but not yet at C.I.P. 2.

(7) In the event of an expected meeting of vessels between the downstream end of the lower approach wall and C.I.P. 2, the downbound vessel shall be told to remain on channel 14 (156.7 MHz) until the meeting has been completed.

(8) After the meeting, the downbound vessel shall call "Seaway Beauharnois" before switching to channel 10 (156.5 MHz).

Communication - Ports, Docks and Anchorages

65.(1) Every vessel entering or leaving a lake port shall report to the appropriate Seaway station at the following check points:
   a. Toronto and Hamilton—
      one mile outside of harbour limits; and
   b. other lake ports—
      when crossing the harbour entrance.

(2) Every vessel arriving at a port, dock or anchorage shall report to the appropriate Seaway station, giving an estimated time of departure if possible, and at least four hours prior to departure, every vessel departing from a port, dock or anchorage shall report in the same way giving its destination and the expected time of arrival at the next check point.
### TABLE OF SPEEDS

Maximum Speed Over the Bottom  
(Miles per Hour)

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Col. III</th>
<th>Col. IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Entrance</td>
<td>Lake St. Louis</td>
<td>12(10.4 knots)</td>
<td>12(10.4 knots)</td>
</tr>
<tr>
<td>South Shore Canal</td>
<td>Buoy 13A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake St. Louis</td>
<td>Lower Entrance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buoy 13A</td>
<td>Beauharnois Lock</td>
<td>18(15.5 knots)</td>
<td>18(15.5 knots)</td>
</tr>
<tr>
<td>Upper Entrance</td>
<td>Lake St. Francis</td>
<td>10 upbd(8.6 knots)</td>
<td>10 upbd(8.6 knots)</td>
</tr>
<tr>
<td>Beauharnois Lock</td>
<td>Buoy 27F</td>
<td>12 dnbd(10.4 knots)</td>
<td>12 dnbd(10.4 knots)</td>
</tr>
<tr>
<td>Lake St. Francis</td>
<td>Lake St. Francis</td>
<td>18(15.5 knots)</td>
<td>18(15.5 knots)</td>
</tr>
<tr>
<td>Buoy 27F</td>
<td>Buoy 87F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake St. Francis</td>
<td>Snell Lock</td>
<td>10 upbd(8.6 knots)</td>
<td>9 upbd(7.8 knots)</td>
</tr>
<tr>
<td>Buoy 87F</td>
<td></td>
<td>12 dnbd(10.4 knots)</td>
<td>12 dnbd(10.4 knots)</td>
</tr>
<tr>
<td>Eisenhower Lock</td>
<td>Richards Point</td>
<td>13(11.3 knots)</td>
<td>12(10.4 knots)</td>
</tr>
<tr>
<td>Richards Point</td>
<td>Morrisburg</td>
<td>15 (13 Knots)</td>
<td>12(10.4 knots)</td>
</tr>
<tr>
<td>Lt. 55</td>
<td>Buoy 84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Morrisburg</td>
<td>Ogden Island</td>
<td>13(11.3 knots)</td>
<td>12(10.4 knots)</td>
</tr>
<tr>
<td>Buoy 84</td>
<td>Buoy 99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ogden Island</td>
<td>Blind Bay</td>
<td>15(13 knots)</td>
<td>12(10.4 knots)</td>
</tr>
<tr>
<td>Buoy 99</td>
<td>1/2 mi. east of Lt. 162</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blind Bay</td>
<td>Deer Island</td>
<td>13(11.3 knots)</td>
<td>12(10.4 knots)</td>
</tr>
<tr>
<td>1/2 mi. east of Lt. 162</td>
<td>Lt. 186</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deer Island</td>
<td>Bartlett Point</td>
<td>10 upbd(8.6 knots)</td>
<td>9 upbd(7.8 knots)</td>
</tr>
<tr>
<td>Lt. 186</td>
<td>Lt. 227</td>
<td>12 dnbd(10.4 knots)</td>
<td>12 dnbd(10.4 knots)</td>
</tr>
<tr>
<td>Bartlett Point</td>
<td>Tibbetts Point</td>
<td>15(13 knots)</td>
<td>12(10.4 knots)</td>
</tr>
<tr>
<td>Lt. 227</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Junction of Canadian Middle Channel & Main Channel abreast of Ironsides Is. 13(11.3 knots) 11(9.5 knots)

Lock I Outer Piers, Welland Canal Port Weller Harbor 9(7.8 knots) 9(7.8 knots)

Port Robinson Ramey's Bend through the Welland By-Pass 9(7.8 knots) 9(7.8 knots)

All other canals 7(6.1 knots) 7(6.1 knots)

*Maximum speeds at which a vessel may travel in identified areas in both normal and high water conditions are set forth in this Schedule. The Corporation and the Authority shall, from time to time, designate the set of speed limits which is in effect. The maximum speeds set forth in the Schedule shall always be subject to specific instructions to a particular vessel.
# SCHEDULE III

## C.I.P. and Check Point

### Upbound Vessels

<table>
<thead>
<tr>
<th>C.I.P.</th>
<th>Message Content</th>
<th>Station of call</th>
<th>Message Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.I.P.2 - Entering Sector 1</td>
<td>Seaway Beauharnois Ch.14</td>
<td>1. Name of vessel</td>
<td>6. Pilot requirement-Lake Ontario</td>
</tr>
<tr>
<td>C.I.P.3 - (order of passing through established)</td>
<td>Seaway Beauharnois Ch.14</td>
<td>1. Name of vessel</td>
<td>2. Location</td>
</tr>
<tr>
<td>Exitting Upper Beauharnois Lock</td>
<td>Seaway Beauharnois Ch.14</td>
<td>1. Name of vessel</td>
<td>2. Location</td>
</tr>
<tr>
<td>C.I.P. 7- Leaving Sector 1</td>
<td>Seaway Beauharnois Ch.14</td>
<td>1. Name of vessel</td>
<td>2. Location</td>
</tr>
<tr>
<td>5. C.I.P. 7- Entering Sector 2</td>
<td>Seaway Eisenhower Ch.12</td>
<td>1. Name of vessel</td>
<td>2. Location</td>
</tr>
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<td>C.I.P. 8- (order of passing through established)</td>
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| 37. Cape Vincent       | Seaway Clayton  | 1. Name of vessel  
                       | Ch. 13           | 2. Location  
                       |                 | 3. ETA Whaleback Shoal  or river port |
| 38. Wolfe Is. Cut (Quebec Head) - Vessels entering Main Channel | Seaway Clayton  | 1. Name of vessel  
                       | Ch. 13           | 2. Location  
                       |                 | 3. ETA Whaleback Shoal  or river port |
| 39. Whaleback Shoal - Leaving Sector 4 | Seaway Clayton  | 1. Name of vessel  
                       | Ch. 13           | 2. Location |
| 40. Whaleback Shoal Entering Sector 3 | Seaway Iroquois | 1. Name of vessel  
                       | Ch. 11           | 2. Location  
                       |                 | 3. Destination  
                       |                 | 4. Drafts, fore and aft  
                       |                 | 5. Cargo |
| 41. C.I.P. 14          | Seaway Iroquois | 1. Name of vessel  
                       | Ch. 11           | 2. Location |
| 42. C.I.P. 13          | Seaway Iroquois | 1. Name of vessel  
                       | Ch. 11           | 2. Location |
| (order of passing through established) |                 |                 |
| 43. Exiting Iroquois Lock | Seaway Iroquois | 1. Name of vessel  
                       | Ch. 11           | 2. Location  
                       |                 | 3. ETA C.I.P. 10  
                       |                 | 4. Harbour or river pilot requirement - St. Lambert |
| 44. C.I.P. 10 - Leaving Sector 3 | Seaway Iroquois | 1. Name of vessel  
                       | Ch. 11           | 2. Location  
                       |                 | 3. ETA C.I.P. 10 |
| 45. C.I.P. 10 - Entering Sector 2 | Seaway Eisenhower | 1. Name of vessel  
                       | Ch. 12           | 2. Location |
| 46. C.I.P. 9 - (order of passing through established) | Seaway Eisenhower | 1. Name of vessel  
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<td>49. C.I.P. 6- Entering Sector 1</td>
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<td>Seaway Beauharnois Ch. 14</td>
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<td>Seaway Beauharnois Ch. 14</td>
<td>1. Name of vessel 2. Location 3. Confirm Harbour or river pilot requirement- St. Lambert 4. Montreal Harbour Berth Number 5. VHF requirement- St. Lambert</td>
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<td>52. St. Lambert Lock to C.I.P. 2- Leaving Sector 1</td>
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<td>Table 5: Humidity Data</td>
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Advances in technology

The Federal Republic of Germany has now 14 years of experience with dedicated surveillance systems for the new family of radar in the coastal waters and estuaries of the river. Investigations were carried out on behalf of the operators for the new system. The results of these investigations and the technical realizations are reported.

4. Introduction

Soon after the end of World War II, particularly in Europe, there was a pressing demand to use the latest in the range of the radar set and the possibilities of the new radar at the end of the 1950s and 1960s. New approaches and new systems were not in use yet. The German Federal Republic, for example, was a leader in the development of radar systems which are connected to a network of monitors and control radar stations by radio link. Instructions are given in writing by VHF radio telegraphy.

This concept was actually practiced between 1958 and 1971 along a total of 231 km of coastline up to the Cape, Kiel, and the Nunsinsinsinsininsinsinsininsinsinsininsinsinsinsinsinsinsinsinsinsinsininsinsinsininsinsinsinsinsinsinsinsinsininsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsinsin
Advances in technology
H. J. Haase

1. Summary

The Federal Republic of Germany has now 14 years of experience in the use of surveillance radar for Marine Traffic Systems. For the new family of radar installations starting at the estuary of the river Jade an investigation was carried out on behalf of the operators for the new system. The result of this investigation and the technical solutions are reported.

2. Introduction

Soon after the end of World War II - particularly in Europe - there was a pronounced tendency to use radar as a shore based navigational aid in harbours. Initial investigations in 1952 showed that - on account of the configuration of the German coast and the position of the harbours at the end of up to 127 km long approaches - foreign experience could not be made use of. The concept developed provided for radar centers which are connected to a number of unmanned, remote control radar stations by radio links. Instructions are given to shipping by VHF radio telephony.

This concept was put into practice between 1959 and 1971 along a total of 255 km of waterway on the Elbe, Weser and Ems.

These 15 years of experience form the basis of the technical and operational planning of new radar shore systems for the safety and free flow of the traffic on a further 120 km of waterway on the Jade and Weser the installation of which should be concluded by 1980.

It is interesting how the practical personnel, i.e. the observers in front of the screen assess difficulties and possible technical improvements in a radar system. For this reason questionnaires were prepared with 28 proposed measures regarding detail. By crossing 5 subsequent columns it was intended to carry out an assessment of measures and difficulties using the following rating code:

* Bundesverkehrsmiisterium, Seezeichenversuchsckfeld Koblenz
1. There is no difficulty; the measure stated is considered a disadvantage. (Rating: -1)
2. There is no difficulty; the measure stated is not necessary. (Rating: 0)
3. There is only slight difficulty; the measure is not essential. (Rating: +0.5)
4. There is medium difficulty; the measure is desirable. (Rating: +1)
5. There is considerable difficulty; the measure is essential. (Rating: +2)

Evaluation of 42 more or less completely filled in questionnaires as well as the additional remarks showed that incomplete filling in was partly a result of difficulty in envisaging the measures described. A certain disinclination towards measures for improvement was also felt (e.g. comment of a pilot "if they do all that we'll be superfluous here.")

The summary below shows the proposed 28 measures and questions in the sequence of maximum positive to negative rating.

<table>
<thead>
<tr>
<th>Consecutive Number</th>
<th>Proposed Measure or Question</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Less wave clutter</td>
<td>+ 50</td>
</tr>
<tr>
<td>2</td>
<td>Increased radar range for buoys at present bad as from approximately 10 km (average of information)</td>
<td>+ 46.5</td>
</tr>
<tr>
<td>3</td>
<td>Less rain clutter (In previous polling rain clutter was given low rating)</td>
<td>+ 45.5</td>
</tr>
<tr>
<td>4</td>
<td>Increased radar range to pick up small vessels at present bad at approximately 11 km (average of information)</td>
<td>+ 42.5</td>
</tr>
<tr>
<td>5</td>
<td>Follower symbols (e.g. circles, squares, figures etc.) which one can push onto a target by hand and which then automatically follow the target so that targets can be distinguished more easily and more targets can be followed.</td>
<td>+ 39</td>
</tr>
<tr>
<td>6</td>
<td>Automatic identification of the calling ship in the radar trace (e.g. cross or circle) to save queries.</td>
<td>+ 38.5</td>
</tr>
</tbody>
</table>
More stable superposition points  + 37.5

More stable radar lines  + 33

Improved clarity by means of different colours on the screen (e.g. targets green, superposition points and lines blue, follower symbols red)  + 32

Superposition of additional information directly onto one corner of the radar trace (e.g. time, level, visibility)  + 31

Less trace interference caused by extraneous radar  + 29

More radar lines to permit improved simulation of navigable water line  + 25.5

More superposition points per screen  + 24

Improvement of report book keeping, e.g. with number keys and letter keys (one presses the number key, then letters of the ship’s name and then has both in the display when required. By means of a transfer key the ship’s name can be transferred to neighbouring screens without keying in again.)  + 24

Improvement of address equipment. (Instead of a microphone with flexible stem on the desk
a) " " " on the display unit
b) Headset of conventional type
c) Headset should be lighter
d) Headset should be cordless)

Clearly most people were not entirely satisfied with the existing system in each case, but preference for the microphone or the cordless headset predominates. The breakdown was: 42% for a), 4% for b), 12% for c), 42% for d).

Improved clarity by means of combined large trace display on the wall instead of individual radar traces. (A type of map with superimposed targets)  + 22.5

Automatic position information on board (similar to speaking clock on the telephone). Should it be stated by speaker or visually (luminous figures on an instrument to be carried on board)?

Acoustic : 55 %
Visual : 45 %

Reduced VHF range to prevent crosstalk  +20
17 Identification of superposition points (e.g. short stroke or buoy name) +16

18a Automatic position information in the radar center: automatic system measures cross deviation (in relation to the rad. line) and distance (from buoys or course change) of ships being guided and automatically transmits this by VHF (similar to speaking clock on the telephone). Observer only needs to observe and transmit traffic situation. +13

18b Brighter radar trace (similar to TV image) +13

18c Supplementary to large trace display automatic advance calculation of situation: on request (pushbutton) it is indicated where important ships picked up will be in a certain advance period. +13

18d Increased VHF range to obtain improved radio contact with ships.

19 Automatic danger warning: if ship's course will result in risk of accident (collision, grounding), this is indicated in the radar trace (e.g. flashing signs on ship). +10

20 Simple combined display in addition to the individual radar traces, e.g. navigable water course as line on a map; the position of important ships is superimposed. +7

21 VHF crosstalk could be prevented if the VHF channels were not in multiple use. Then, however, less channels would be available to each radar center so that for example two screens would only have one channel. Which of measures numbers 5, 6, 9, 14, 18a, 18c, 20 would permit one observer with one VHF channel to observe two screens? VHF crosstalk could be prevented if the VHF channels were not in multiple use. Then, however, less channels would be available to each radar center so that for example two screens would only have one channel. Which of measures numbers 5, 6, 9, 14, 18a, 18c, 20 would permit one observer with one VHF channel to observe two screens?

Consideration of this was declined by several pilots without suggesting any measures (cross against "disadvantage" or written "no"). Otherwise, the following were suggested here:

No. 14 = 10 x
No. 5  =  9 x
No. 6  =  9 x
No. 18a =  8 x
No. 19 =  2 x
No. 9  =  1 x
No. 18c & 20 =  0 x

70
Replacement of the radar lines by rows of dots

No rating: at what interval (in minutes) is new statement of position and description of traffic (oncoming vessels, vessels travelling in same direction etc.) desired in each case on board?
The answers varied considerably. As an average the following was established:
Position every 3.3 minutes,
situation every 4.1 minutes.
Frequently the answer was: depends on circumstances (speed of ship, course of navigable water). In critical situations continuously, otherwise every approximately 500 meters.

The additional remarks can be summarized as follows:
Considerable complaint was lodged concerning increased crosstalk disturbance from extraneous channels since the introduction of the 25 kHz raster (increased intermodulation sensitivity of transistorized sets).
The automatic advance course calculation and danger warning is suspect by the pilots as being uncertain (ships frequently change course in the area, have narrow intervals, intermittently collision course, so that advance calculation will not be correct and danger warning will be continuous).
The frequently high noise level on the bridge (on occasions sound generators operated) is against acoustic position information on board. Against visual methods the objection is raised of the visual strain on the pilot (advance image, radar, helm indicator etc.); both types of imparting the information recommended.
Special marking of pilot vessels, dredgers and recovery vessels (floating cranes) is desired. The basic requirement for restricting the situation information is that every vessel reports, receives a follower number and can be addressed immediately if required. In some sections curved radar lines would be desirable.
To summarize, the following weaknesses are apparent in the existing shore radar chains:

1. The radar trace is frequently impaired by wave clutter, sometimes also by rain chatter. Weak targets are difficult to pick up at ranges over 15 km (\( \leq 10 \text{ m}^2 \)).

2. The analog system widely used until now leads to instability and inaccuracy of the auxiliary information superimposed (radar lines, buoys).

3. The observer is faced with a series of problems during guidance:
   3.1 Identification of a calling ship on the screen
   3.2 Risk of confusing several ships being guided, i.e. interalia being constantly tied to one screen.
   3.3 Loading caused by constant estimation of transverse and longitudinal distances.
   3.4 Risk of confusing floating see marks.

These problems conflict with economical use of personnel.

Taking into account this existing experience and knowledge as regards the possibility for partly automating guidance operation it has also been attempted to determine the guidance capacity necessary, i.e. the number of observers and information transmission paths in the form of VHF channels.


For this estimate it was necessary to determine numerically the area conditions (length, number of course changes, traffic density) as well as type, extent and organization of the guidance information.

The area length of the planned shore radar chains is:

- Unterweser 59 km
- Jade 60 km
The area traffic density is:

<table>
<thead>
<tr>
<th>Area Transit Speed</th>
<th>Maximum</th>
<th>10 sm/h</th>
<th>15 sm/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unterweser</td>
<td>45</td>
<td>35</td>
<td>ships</td>
</tr>
<tr>
<td>Jade at present</td>
<td>18</td>
<td>17</td>
<td>&quot;</td>
</tr>
<tr>
<td>Jade future</td>
<td>21</td>
<td>19</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unterweser</td>
</tr>
<tr>
<td>Jade at present</td>
</tr>
<tr>
<td>Jade future</td>
</tr>
</tbody>
</table>

For the number of vessels to be guided it has been assumed that 80% or more of the vessels are equipped with VHF ship systems. It should be required that with average area traffic density this 80% can receive radar guidance. At maximum area traffic density it should be possible to guide at least 50% of all ships whilst the others listen in or can follow the vessel in front being guided with the aid of the ships radar.

From this we obtain the following figures for vessels to be guided.

<table>
<thead>
<tr>
<th>Average</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 sm/h</td>
<td>15 sm/h</td>
</tr>
<tr>
<td>Unterweser</td>
<td>20</td>
</tr>
<tr>
<td>Jade at present</td>
<td>13</td>
</tr>
<tr>
<td>Jade future</td>
<td>14</td>
</tr>
</tbody>
</table>

The maximum for the Jade is only given for the sake of completeness. On account of the lower traffic fluctuations the 50% maximum value is below the 80% average value.

With existing guidance practice the vessels being guided receive position information and traffic information cyclically. With the position information a ship receives its position with cross deviation to the navigable water axis with longitudinal distance from the nearest navigable water buoy. The traffic information gives the ship a description of the traffic situation in his surroundings (oncoming vessels, vessels in same direction, vessels at anchor etc.). From the evaluation of the tape recordings one has established for the position information a time requirement of 10 seconds and for the traffic information 15 seconds, i.e. a total of 25 seconds.
From the length of the navigable water sections, the number of change of course points and the speeds of approach the following advice cycles are obtained:

<table>
<thead>
<tr>
<th>Speed</th>
<th>10 sm/h</th>
<th>15 sm/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time cycle of traffic information</td>
<td>9 minutes</td>
<td>6 minutes</td>
</tr>
<tr>
<td>Time cycle of position information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unterweser</td>
<td>4.5 &quot;</td>
<td>3 &quot;</td>
</tr>
<tr>
<td>Jade</td>
<td>4.2 &quot;</td>
<td>2.8 &quot;</td>
</tr>
</tbody>
</table>

It is assumed here that it is necessary to issue position information 2 - 3 times per navigable water section.

From this information it is now possible to derive the number of observers and VHF channels necessary.

Non-automated guidance operation

With non-automated information the number of channels necessary will be the same as the number of observers. Whilst the individual assessment of the constantly-changing traffic situation is the prerogative of the observer, the position information can under circumstances be automated by the position of ships picked up being determined automatically by the use of computers. This position information can either be transmitted as synthetic speech information or as remote control signal which produces a numerical display of the position on suitably modified VHF ship sets. Thus, the number of observers necessary is reduced where, for example, parallel information paths are available, in the traffic information to overall information proportion, theoretically to the following values:

<table>
<thead>
<tr>
<th>Area</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 Kn</td>
<td>15 Kn</td>
</tr>
<tr>
<td>Jade at present</td>
<td>0.41</td>
<td>0.4</td>
</tr>
<tr>
<td>Jade future</td>
<td>0.41</td>
<td>0.4</td>
</tr>
</tbody>
</table>

A = Proportion of traffic information/overall information
B = Theoretical number of observers

Semi-automated guidance operation

In practice, however, an observer cannot issue traffic information on different area sections in a constant flow of speech and over different VHF channels.
For a future traffic safety system one should, there­fore, proceed from the following assumptions:

For maximum size ships automatic position information from the primary radar echo is unsafe as it is not known to what point of the surface echo the automatic position information in question refers. Here, responders in combination with a data display could offer advantages. They represent as reference target a point target, permit high data rate of visually displayed data on board and can, therefore, relieve the system of acoustic automatic position information by 10% of the ships to be guided. The observer can, assisted by identification and follower symbols in the radar trace, issue cyclically combined traffic situation reports per area section ~ VHF channel. The time re­quirement of this information per ship can then under certain circumstances be reduced from 15 seconds to 7.5 seconds. In addition, the observer has 7.5 seconds proportionately per ship for observation, i.e. he is speaking on average 50% of the time.

For practical operation it is possible to estimate from this investigation the following requirement for VHF channels and observers:

<table>
<thead>
<tr>
<th>Area / System</th>
<th>Non-automated VHF channels</th>
<th>Observers</th>
<th>Semi-automated VHF channels</th>
<th>Observers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jade at present</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Jade future</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

By means of semi-automation therefore the number of observers could be halved. With the low number of observers (operators) necessary a cost - return analysis must show whether semi-automation is advis­able.

A new traffic safety system - as further development of the existing shore radar chains - should now not only eliminate the existing weaknesses, it should al­so take into account alterations or extensions which contribute to an increase in safety and free flow of traffic. The requirements for a new system should, therefore, in addition to eliminating the weakness­es of the existing system - also be aimed at the solution of surveyable future problems such as for example partial or general traffic control. It has been found that the definition of requirements of this type is difficult. The practical man in the nau­tical field prefers to work from the existing system.
The technician recognizes many variants of a new system as being realizable which then raises the question as to how much of it is operationally necessary.

Consideration of the above accounts shows that there are two groups of requirements.

1. Requirements which are area-dependent, can be clearly defined and can in the main be fulfilled by suitable hardware. (Phase I)

2. Requirements which depend as regards their weight on the area parameters and can be delimited with less safety both from the technical and from the nautical operational side and can, in the main, be fulfilled by suitable software and thus more flexibly (Phase 2)

With all considerations for a new system the following restricting condition must be noted. In shipping, there is in contrast to aviation no internationally agreed secondary radar system with special ships sets which report on enquiry with the ships name and any additional information. An instrument of this type cannot for reasons of cost be kept available for systems with heavy shipping traffic. Operational reasons as well are against an instrument which is only taken on board when the ship reaches the area. Therefore, only the standard VHF ship system has been included in planning as cooperative ship set.

For the shore radar system, therefore, the ship is a passive partner for VHF direction finding and information transmission the active partner in the traffic safety system.

The planning and installation of the two new systems will take place in the two phases mentioned, the first of which is more of a hardware nature whilst in the second software considerations predominate. Fig. 1 shows the simplified block diagram. The system sections of Phase 2 are edged in heavy lines.
Fig. 1  SIMPLIFIED BLOCK DIAGRAM OF A MODERN SHORE-BASED RADAR
The antenna system has a radiation pattern with \( \leq 0.35^\circ \) half field strength beam width (-3 dB) and is transposable to horizontal, vertical and circular polarization. The transmission system incorporates two identical transmitters with transmission frequencies displaced by approximately 200 MHz. The two transmitters are connected to the antenna by means of two circulators and a diplexer. The transmitters are triggered simultaneously so that in combination with the polarization changeover of the antenna the following time pattern is obtained: frequency diversity: simultaneous; polarization diversity: sequential.

The receiver system incorporates two identical receivers for reception of the approximately 200 MHz displaced transmission frequencies. Coarse compensation of the range dependence of the signal level received is effected by means of gain control (STC) of the linear preamplifier. Initial amplitude and inclination of the STC control function are internally adjustable and can be coupled to clutter-dependent gain control. Signal processing has the following functions:

- Quantization and coding of the amplified radar signal
- Clutter-dependent gain control
- Combination of the signal sequences resulting from frequency and polarization diversity
- Frequency band compression for PCM transmission

According to the wishes of the observers identification bears the rating of 38.5 and is thus well to the fore in order of priority. The use of VHF direction finders is, therefore, being provided for.

Identification can be automated by this means. The cross bearing of a ship requesting VHF guidance (possible today with an accuracy of 0.3° to 0.1°) should be superimposed on the radar trace.

Phase 2 of the new traffic safety system is at present in the stage of definition of requirements.

It is intended to relieve the observer by introduction of identification and follower symbols, automatic position information etc. and thus render personnel application more economical. With it the use of process computers as "traffic computers" will be necessary. A computer requires on the one hand supply of suitable data from the radar system (extraction) and on the other hand suitable programming matched to suit nautical and technical conditions.
From the present assignment:

- conveyance of traffic with the aid of a traffic safety system
- possible partial control of the traffic flow
- at present no ship reporting and assistance of the harbour organization

and by virtue of technical and economic considerations
- limited experience
- limits set by memory and image display capacity

the following configuration of Phase 2 seems advisable as an initial step:

- automatic extraction from ships which are identified by VHF direction finding
- automatic extraction according to identification by observers
- follower symbols
- position information on request
- advance calculation on request
- automatic danger warning will be dispensed with
- the loss of follower symbols will be indicated.
- trial of automatic transmission of position information to ships must be possible by means of program extension.

The course of action outlined above will, to a large extent, satisfy the wishes not dealt with by the existing system and is sufficiently flexible to incorporate future requirements as well within an economical framework.
TECHNOLOGICAL CONSIDERATIONS IN THE DESIGN OF FUTURE
U.K. HARBOUR SYSTEMS

P.F.C. Griffiths*  

1. Introduction

In any consideration of future harbour systems it is necessary not only to review the specification and operational system performance of present systems but also to determine the future needs. To this end we have used various questionnaires to elicit information on future requirements together with a detailed evaluation of the technical limitations of present systems in our role of scientific adviser to the Department of Trade and other Authorities. This has led to a research programme directed towards the solution of some of the outstanding problems inherent in those present systems. This paper includes a review of the technology employed in some current UK systems and a summary of the primary limitations that have been identified. This is followed by some results from our investigations into future surveillance and guidance systems. These include for surveillance, choice of radar frequency and polarisation, position monitoring of floating navigation marks and the optimisation of radar performance for sea clutter rejection. For channel guidance a summary of an assessment of possible systems is included.

2. Review of Present Systems

Our experience of UK harbour systems suggests that the major functions of electronic navigation for the Harbour Authority are:-

a) Surveillance.

b) Guidance.

c) Berthing.

There are fundamental differences in the way in which such systems are operated. At present surveillance provides position data to the Harbour Administration which can be used to increase

*Civil Marine Division, Admiralty Surface Weapons Establishment UK
the effectiveness of traffic flow, particularly in conditions of poor visibility. The output from such a system is in the form of a more detailed information flow between the Harbour Authority and the vessels using that particular Port.

On the other hand, guidance systems are specific aids, provided by the Harbour Authority for the use of both Ship's Masters and Pilots and the data output is not under the control of the Harbour Administration.

A typical operational requirement for a Harbour system is summarised in TABLE 1.

The basic requirement implies that radar will be used as the primary means of data acquisition.

### Surveillance

#### System Data

This would normally cover such questions as a) the limits of the surveillance area b) the maximum and minimum detection range as a function of target size for both fixed and mobile targets c) the bearing and range resolution of multiple targets d) the integrity of the system in adverse environmental conditions eg rain, high sea states, excessive wind etc.

#### Data Display

Features include:-

a) Surveillance area by switched display or multiple displays.

b) Electronic marking of channel limits, and/or prominent harbour navigation features.

c) Synthetic data available on primary surveillance display/s or as an additional feature.

#### Data Processing

Typical requirements are:-

a) Measurement of target range to a specific harbour feature.

b) Target speed.

c) Possibly, range between multiple targets.

### Data Transfer

This could include:

a) Means of transferring the basic radar data from remote sites to a central control centre.

b) Means of disseminating the processed data to shipping within the harbour.

c) Means of storing selected information for future use.
<table>
<thead>
<tr>
<th>Function</th>
<th>Surveillance</th>
<th>Guidance</th>
<th>Berthing</th>
<th>Communications</th>
</tr>
</thead>
<tbody>
<tr>
<td>RANGE (n.m.)</td>
<td>MIN</td>
<td>.05</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>MAX</td>
<td>15</td>
<td>5</td>
<td>0.25</td>
</tr>
<tr>
<td>TARGET</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>COASTLINES,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NAVIGATIONAL</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>MARKS,</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>PILOT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LAUNCHES,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SINGLE POINT</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>MOORINGS.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RESOLUTION</td>
<td>RANGE 75 YDS</td>
<td>RANGE 100 YDS</td>
<td>APPROACH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BEARING ± 1°</td>
<td>OFFSET ± 100 FT</td>
<td>SPEED 2/3 KT</td>
<td></td>
</tr>
<tr>
<td>AREA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HARBOUR AND</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>APPROACHES</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENVIRONMENT</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>HEAVY RAIN.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>SEA STATE 7.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>WIND SPEED 80 mph.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INFORMATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DISPLAY AT</td>
<td>AVAILABLE ON</td>
<td>DISPLAY</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OPERATIONS</td>
<td>SHIPS BRIDGE</td>
<td>ON</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CENTRE WITH</td>
<td>IN DIGITAL</td>
<td>JETTY</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AUTOMATIC</td>
<td>FORM AND</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DATA</td>
<td>PORTABLE.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PROCESSING.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>REMOTE SYSTEM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>REQUIRES DATA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TRANSFER TO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OPERATIONS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CENTRE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
System Availability

Such questions as continuity of the surveillance service need to be considered. This determines the reliability requirement of the remote radar sites and data transfer system.

This consideration of the major aspects of the operational requirement lead to the production of a system technical specification.

A typical specification for a harbour radar is shown in TABLE 2.

With few exceptions the preferred frequency has been X Band together with linear polarization. The service area is rarely greater than 10 n.m. Specific differences from conventional shipborne radar are in aerial design, the elimination of facilities concerned with own ship motion, and the distance separation between the aerial and transceiver from the display and data processing system.

The aerial shore site allows considerable increase in size over the normal shipborne equipment and therefore increased system gain and bearing discrimination. The distance separation between aerial and display provides special problems in data transmission and the reliability of remote automatic equipment with the consequential increase in cost.

The display and data processing system may require the provision of special facilities e.g. visual display of channel approach limits, automatic range and bearing measurement of vessels from known fixed locations etc.

Special features to provide improved performance in adverse weather conditions are concerned with electronic means of reducing the degrading effects of rain and sea state on radar performance.

ASWE has been involved in the assessment, design, specification and acceptance of such systems since 1946. In the UK these have included Southampton, Milford Haven, Liverpool, Medway, Humber to name but a few. Our work has covered both Civil and Military harbour systems and we are presently engaged at Harwich, Orkney Bay and with the Channel Navigation Information Service at St. Margarets Head and Dungeness.

Guidance

A Harbour Authority may have a particular operational requirement which cannot be satisfied by conventional radar surveillance. One such requirement concerns the guidance of large vessels through confined waters, and in detail requires the measurement of ship range, speed and offset within a harbour channel to an accuracy not achievable by a surveillance radar, together with immediate real time availability to the Master and Pilot of a ship in transit through that narrow harbour channel.
<table>
<thead>
<tr>
<th>UNIT</th>
<th>GAIN (dB)</th>
<th>BEAMWIDTH (degrees) (-3 dB)</th>
<th>SIDELOBSES (dB)</th>
<th>ROTATION (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HORIZONTAL</td>
<td>VERTICAL</td>
<td>INSIDE ± 10°</td>
<td>OUTSIDE ± 10°</td>
</tr>
<tr>
<td>AERIAL SYSTEM</td>
<td>41</td>
<td>.3</td>
<td>15</td>
<td>-23</td>
</tr>
<tr>
<td>TRANSMITTER</td>
<td>PEAK POWER (kw)</td>
<td>FREQUENCY</td>
<td>PULSE LENGTH (μsec)</td>
<td>P.R.F.</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>HARBOUR BAND (a) 0.05</td>
<td>(b) 0.5</td>
<td>1000</td>
</tr>
<tr>
<td>RECIPIENT</td>
<td>NOISE FACTOR (dB)</td>
<td>RECEIVER CHARACTERISTICS</td>
<td>VIDEO BANDWIDTH (MHz)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NOT GREATER THAN 10</td>
<td>LOGARITHMIC</td>
<td>NOT LESS THAN 14</td>
<td></td>
</tr>
<tr>
<td>DISPLAY SYSTEM</td>
<td>NUMBER P.P.I.</td>
<td>SPOT SIZE REFLECTION</td>
<td>RANGE SCALES CENTERING</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 WITH</td>
<td>(ins)</td>
<td>(mm)</td>
<td>FLOTTERS</td>
</tr>
<tr>
<td>CHANGEOVER SWITCH</td>
<td>16</td>
<td>16</td>
<td>0.8</td>
<td>YES</td>
</tr>
<tr>
<td>CALIBRATION RINGS</td>
<td>RANGE AND BEARING SIGNALING</td>
<td>RECEIVER TUNING MEASUREMENT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AT LEAST 3 PER RANGE</td>
<td>DIGITAL READOUT</td>
<td>YES (MAGIC EYE OR METER)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Traditional, non instrumented, methods of harbour channel approach navigation make use of transit lines and buoys to delineate the channel centre and buoys to mark the edges, aided by lights at night. Such procedures can and do work successfully in clear visibility. During periods of low visibility however, (fog, heavy rain, snow etc) they can become inadequate making shipping movements potentially unsafe. Again, in an urban environment, the integrity of distinguishing transit lights can be degraded by the interfering background confusion and glow from street lamps, etc. The decision as to when visual information is degraded to the point of being inadequate involves a difficult judgement for the Master and Pilot considered in conjunction with other navigation factors. Such factors are not realistically catered for by the last ditch decision of Harbour Authorities to close the port. Further, the situation can become hazardous if visibility conditions deteriorate once a vessel has committed itself to an approach channel.

These visual aids do not provide particularly accurate information as to range from the next point of commencing manoeuvre, true progress over the ground, or offset distance from the channel centre. Improvement in the accuracy of such information could assist when aligning a vessel before executing a manoeuvre. In practice a Pilot may use supplementary information available from ship systems. The ship's radar can be used to determine position along channel.

A ship's log may give relative speed information, which when supplemented by the knowledge of the tidal flow might provide some information. However, logs measuring water flow are subject to severe errors in restricted channels. Doppler sonar logs, in shallow water, can give the true speed over the ground, but are not, as yet, widely fitted to ships. Occasionally the ship's compass may be used to determine ship's heading. There are disadvantages, from the Pilot's point of view, in relying on such apparatus, even when fitted to the ship.

a. Such equipment may be uncalibrated or inoperative.

The Pilot may need to ask for the information, with the possibility of a language barrier.

The quality of information, especially from the radar, will to some extent be operator dependent.

d. The quality of information required by the Pilot differs from that required for navigation in more open waters.

Therefore any additional apparatus, designed to aid approach channel navigation should preferably be an independent equipment which the Pilot can consult as required. This information may also need to be available to the Master to enable him to judge the soundness of navigation procedure in his capacity of being in charge of and responsible for his ship.

Design Concepts

The design concepts of an Approach Aid for use by the Pilot
should be,

a. To provide, under conditions of inadequate visibility, supplementary information for assistance to navigate a narrow channel in reasonable safety, the total information being as effective as that otherwise available in clear visibility.

b. To provide the navigational information by means independent of the ship's normal navigation facilities but under the responsible control of the Pilot.

c. To supplement the information available to the Pilot in clear visibility where this can be shown to contribute overall to significantly improved safety of navigation.

d. To offer options of additional facilities or increased performance leading to commercial advantage without degradation of navigational safety.

Benefits

Apart from the navigational benefits afforded to the Pilot, Harbour Authorities and ship operators may benefit commercially, other than from increased safety. Some possible benefits might be:

a. To maximise the use of approach channel width, or conversely minimise dredging requirements.

b. The traffic handling capacity of the harbour may be increased.

c. The ability to enter or leave harbour in adverse visibility conditions may reduce turn round times and so reduce disruption of sailing schedules.

Operational Requirements

Discussions with some 20 Harbour Authorities has identified the following requirements.

a. Position along Channel measured as the distance from reference points along the Channel.

b. The vessel speed measured as a range rate along the Channel.

c. The across channel position measured as an offset distance from the channel centre.

d. Shipborne equipment should be portable. Harbour Authorities require the maximum number of types of vessel to be able to use the port facilities. Equipment which is carried aboard by the Pilot, and independent of all ships systems (Radar, Radio, Compass, Power Supplies etc.) could be used by any piloted vessel. With such a system even those vessels
calling at the port only very infrequently would be catered for.

There may be other subsidiary requirements, such as the centre and rate of turning of the vessel, lateral speed etc. These requirements may (possibly not by simple means), be derived from the previous information, if such values are known to the required accuracy (i.e. lateral speed would be an offset position rate).

Accuracy and Coverage

The accuracy to which this information should be displayed and the coverage required will depend on the type of vessel requiring guidance and the particular harbour approach channel. A preliminary assessment of channel guidance requirements is in TABLE 3.

<p>| TABLE 3 |
|-------------------|-------------------|</p>
<table>
<thead>
<tr>
<th><strong>Accuracy</strong></th>
<th><strong>Coverage</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>$\sim 0.01$ n.m.</td>
</tr>
<tr>
<td>$\sim 0.25$ kts</td>
<td>0.25 to 15 kts</td>
</tr>
<tr>
<td>Offset</td>
<td>$\sim 30$ ft</td>
</tr>
<tr>
<td>$\pm 1,000$ ft</td>
<td>$\geq 2$ per min</td>
</tr>
</tbody>
</table>

Operational Implications

The implication of these requirements and their comparison with the accuracy of other methods of channel navigation shows that:

a) Position Along Channel

Visual leading line systems do not provide distance information. In such a situation position is usually judged by the relative locations of fixed points (buoys, buildings etc) supported by periodic lateral transits. During periods of reduced visibility this information may be seriously degraded.

Radar information on range from well recognised defined targets can be readily accurate to 0.01 n.m. from many civil marine navigation radar installations. The problem lies in the Pilot relying on such information being accessible on the bridge of any ship requiring pilotage, and the availability of suitable targets (buoys do not have
such positional stability).

The maximum range needed will depend on the length of the approach channel and a value of 10 n.m. should cover most circumstances.

b) Ground Speed

Both normal visual information and navigation radars cannot supply true speed information to anything like the accuracy required in piloting large vessels, nor can required information update rates be achieved. Such accuracy and update of variations, is extremely important where, with very large vessels, a speed of 1 knot in error may require a considerably greater stopping distance. A Pilot aid will need to display speed accurate to 0.25 knot over the range of 0 to 15 knots.

c) Offset

The best visual transit systems can indicate the centre of an approach channel to about a minute of arc. With reasonable visibility, position accuracies of better than about 0.5 degrees are usual. Offset error being proportional to range, at 10 nautical miles this value will correspond to an offset of 600 ft. Other lead techniques, such as sector lights might well have errors exceeding twice this value.

Clearly there is a relationship between the length of channel, the width of the channel, the beam of the ship and the accuracy of measurement needed.

Where the angular accuracy, $\psi$, of a transit is considered, this must relate to the linear offset accuracy, $\sigma$ at maximum range ($R_m$) and is given by

$$\sigma = R_m \psi$$

If $\psi$ can be estimated for the transit system then $\sigma$ can be calculated. A Pilot is able to judge his angle to the lead $\theta$ to an accuracy of $\psi$. A linear offset, OB will then be subject to the error $\sigma = R \psi$. To reduce offset error $\sigma$, the angular accuracy must be improved. An instrumented channel approach aid, for bad visibility, would need to provide an equivalent accuracy in terms of a value of $\sigma \leq R_m \psi$. An adequate working relation between the channel width ($w$) the ship beam and offset accuracy ($\sigma$ being the first standard deviation) is

$$w = 4 \times \text{Beam} + 20\sigma$$
For a beam of 200 ft

\[ w = \begin{cases} 1,000 \text{ ft} & \text{for } \sigma = 100 \text{ ft} \\ 860 \text{ ft} & \text{for } \sigma = 30 \text{ ft} \\ 820 \text{ ft} & \text{for } \sigma = 10 \text{ ft} \end{cases} \]

This equation shows that to handle larger and wider ships, either \( \sigma \) must be reduced or the channel must be widened. Conversely, reducing \( \sigma \) should enable similar ships to pass down a narrower channel, and might possibly involve less dredging work. A need for extending operations safety into poor visibility conditions emphasises an instrumented approach.

**Update Rate**

In a given time interval a vessel should not move by a distance significantly greater than range and offset accuracy requirements. A vessel moving at 10 knots will cover about 1,000 feet/minute. An update rate of once every 2 minutes therefore means that the range resolution of 0.01 nautical mile is exceeded at least five times. Such a resolution can usually be tolerated since present visual systems are much worse; higher update rates and slower speeds can make the error smaller.

The accuracy to which the range is displayed is arbitrary, since the accuracy to which range must be measured to give accurate speed information far exceeds the range specification requirements.

Consider the situation in which a vessel is at range \( R_1 \) at time \( t_1 \) and at range \( R_2 \) at time \( t_2 \). If \( t_2 - t_1 \) is the update time \( t \), then the average speed of the vessel in the time interval will be \( \frac{R_2 - R_1}{t} \).

Now, if the range resolution of the equipment is \( Y \); \( R_1 \) and \( R_2 \) will be known only to \( \pm Y \). The maximum and minimum speeds obtained will then be

\[
\frac{(R_2 + Y) - (R_1 - Y)}{t} = \frac{R_2 - R_1}{t} \pm 2Y
\]

\( = \) True Speed + Speed error

For \( t = \frac{1}{2} \) minute and speed error less than 0.25 knot.

\[ 2 \times 120 \times Y < 0.25 \]

\[ Y < 1 \times 10^{-3} \text{ n.m.} \approx 6 \text{ feet} \]
which is an order of magnitude smaller than the required specification and is independent of the actual value of range.

System Techniques for Channel Guidance

Various position fixing techniques have been developed, particularly in the fields of aviation and defence. Some of these techniques may be applicable to the civil marine requirements. A summary of such techniques is shown in TABLE 4.

Leader Cables

Such a technique is promising for guiding land and aircraft, their applicability to the civil marine is open to considerable doubt.

a) Advantages

i) Winding channels can be covered.

ii) A line of position can be defined and left and right information can be identified.

iii) Under constant physical conditions (i.e., no change in water depth etc.), offset accuracies of a few feet are predicted.

b) Disadvantages

i) The position of the cable can be altered by
   a) Tidal movement.
   b) Dredging, anchors and trawls.

ii) Search coils need to be fitted to each vessel requiring guidance.

iii) The offset calibration can be varied by
   a) The depth of water.
   b) Other electro-magnetic power systems.
   c) The presence of large ferrous objects (other vessels in channel, wrecks etc.).

iv) Position along track and speed information is not available (occasional range marks 1 per km may be possible.

Range - Range Techniques

If an accurate reference ranging system is available the position of a target vessel can be determined by range
<table>
<thead>
<tr>
<th>TECHNIQUE</th>
<th>SYSTEMS</th>
<th>BASIC ACCURACY</th>
<th>SHIP INDEPENDENT EQUIPMENT</th>
<th>COMPUTATION REQUIREMENT</th>
<th>RELATIVE COST</th>
<th>OVERALL SUITABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RANGE</td>
<td>SPEED</td>
<td>OFFSET</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEADER CABLES</td>
<td>-</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>LOW</td>
</tr>
<tr>
<td>RANGE/RANGE</td>
<td>HYBRIDIC</td>
<td>YES</td>
<td>POSSIBLE</td>
<td>YES</td>
<td>POSSIBLE</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>RADAR TRANSPONDER</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>HIGH</td>
<td>HIGH</td>
</tr>
<tr>
<td>RANGE/BEARING</td>
<td>MONOPULSE</td>
<td>POSSIBLE</td>
<td>POSSIBLE</td>
<td>YES</td>
<td>YES</td>
<td>LOW</td>
</tr>
<tr>
<td>RADAR TRANSPONDER</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>LOW</td>
<td>MEDIUM</td>
</tr>
</tbody>
</table>
triangulation techniques. Sufficient accuracy could reveal offset distance from the channel axis and speed as a position rate.

Hyperbolic range difference systems

Systems, such as Decca Navigator, Loran C and OMEGA are valuable position fixing techniques for oceanic and coastal navigation. In the confined waters of harbour approach channels they do not fit the user operational requirements for an Approach aid. However, a localized system such as HIFIX may more closely approach these requirements.

Advantages

a) Position accuracy of about 6 feet.

b) The position measuring and display equipment might be made portable.

Disadvantages

a) Distortion of the radio frequency field near metal objects may degrade the accuracy of measurement, and lines of position (LOP) may not be uniquely defined.

b) Computation of 'distance run' and hence range rate is not available from present equipment. This could be added after suitable development.

c) The equipment must be 'set up' each time at a known position (ie at a berth or jetty).

d) A receiving antenna, mounted in an open position on the ship is required.

Laser Techniques

Laser techniques can undoubtedly give the range resolution required. However, problems with transmission during low visibility, for example, may make such potential systems unattractive.

Radar Techniques

The use of radar type ranging equipment is a well proven technique. In interrogator/transponder configurations, with the use of multiple ranging and averaging, range resolutions of less than one foot are possible.

Advantages

a) Large area coverage of approach channels, possibly including bends.
b) Information as to vessel position and speed and possibly identity, course and intentions could be made available to a shore based Control room.

c) Shore equipment may be used by more than one vessel at a time (by using sequential interrogation or time sharing).

Disadvantages

a) An omnidirectional interrogating and range receiving aerial would need to be fitted to each vessel requiring guidance.

b) The apparatus required to compute the vessel position may not be portable by the Pilot.

c) Computing facilities, if on shore, would require data transfer links between ship and shore - Modern computer technology could make such equipment portable.

Typical System

A diagram of typical interrogation and information transfer sequences using a range/range system with on ship mounted interrogator is shown in FIGURE 1. Other configurations, with shore based interrogators are of course, possible.

Range/Bearing Techniques

A position fixing system that is commonly used in tracking applications is that of measuring the range and bearing of the target. Using a single range transponder and a single bearing measurement equipment ashore, there are two basic configurations that can be considered for use as a channel aid.

i) With the transponder and angle measuring equipment located at a suitable position on the centre line of the approach channel.

ii) With the range/bearing transponder situated at a suitable distance normal to the channel axis.

On balance it is expected that the 'On Axis' solution would more nearly fit the majority of operational requirement.

Advantages

a) The data processing for on-axis configuration is less involved and can be made Pilot portable.

b) The angular coverage of an on-axis system would be much
CHANNEL AID
RANGE/RANGE SYSTEM

FIG 1

SHORE COMPUTER — Position, Speed, Course, Identity

Identity and Range

SHIP

SHORE CONTROL ROOM — Position, Speed, Course etc

Range Interrogations

1 2 n

SHORE RANGING TRANSPONDERS
less than the off-axis. Less electronics for a given accuracy would therefore be required. The narrower angular coverage would also mean that the shipborne equipment can have a higher gain aerial. The off-axis system might require a well sighted omnidirectional aerial to cope with the large angular changes expected along a channel.

c) The overall accuracy of the 'On Axis' system would be expected to be better.

If accurate offset information is required a particular distance from a shore site, the off-axis system may possibly be better.

d) If only Range and Speed are required in a particular application the bearing measuring equipment can easily be omitted from the 'on axis' system.

Disadvantages

The major disadvantages with a simple range/bearing technique is that only straight channels can be covered.

The bearing accuracies required to give an offset resolution of 30 feet at 10 nautical miles range is 0.025 degrees.

Bearing Measurement Techniques

There are three parameters of an electro-magnetic signal, which have been used to measure bearing. These are Frequency, Amplitude and Phase.

Frequency

Indicating bearing by change in frequency has been used in 'Doppler Scan' Microwave Landing System (MLS) for use at civil airfields. This system simulates a doppler shift in a transmitted signal by moving the position of the radiation source. In this way the bearing of any point in space is coded by frequency change. The equipment could measure bearing to the required accuracy.

Amplitude

Measurement of bearing by comparing the amplitude received at two or more receiving aerials is used extensively in tracking radars (monopulse systems etc.). Amplitude comparison techniques rely on the fact that the gain of a receiving antenna varies with angle. By comparing the received signal levels in each of two aerials displaced by a few degrees in azimuth an output proportional to angle can be obtained.

Some of the limitations with such a technique are that the output calibration is not linear and that aerial sidelobes can
produce unacceptable ambiguities in a static (no tracking) system. These ambiguities become more numerous closer to the shore transponder since in this region the angular coverage required is at a maximum.

If a search and acquisition process is used and the target tracked (as used with monopulse) the system can only be used for one vessel at a time.

If one requires an angular coverage of more than a few degrees, without ambiguity and without resort to tracking there is likely to be a loss in angular resolution. In general this loss of resolution would be unacceptable for the majority of possible channel aid applications.

Phase

Obtaining bearing angle by measuring phase is a technique that has been chosen by commercial manufacturers when non-tracking systems were required. Two such equipments are the Microwave Aircraft Guidance Equipment (MAGE) manufactured by MEL and the channel aid at Milford Haven manufactured by DECCA.

Advantages

Phase measuring techniques have the following advantages over the other methods.

i) Large angular coverage possible (up to ± 90°).

ii) The theoretical angular accuracy can be determined by size of aerial array used.

iii) Various forms of error minimisation are possible.

iv) Such systems may be used by more than one user at a time.

v) All phase measuring equipment can be situated ashore without the need for complex data links.

We have been specifically concerned with the Channel Approach system at Milford Haven from the initial design concept through to the present acceptance phase. That particular range bearing interferometer system provides range, speed and offset information from a portable unit, taken on board by the Pilot.

The major problems with such a system have been associated with multipath interference from prominent features adjacent to the harbour channels, and future operational requirements will need to take careful heed of such possible problems.

Berthing

Electronic assistance for the berthing of large vessels has been provided in some harbours.
Invariably the essential ship parameter requiring accurate measurement is speed. Various methods including doppler radar and doppler sonar have been developed. To some extent all have limitations both technical and operational.

There is no intention in this paper to examine such systems in detail as no priority operational requirement has yet been identified.

3. Future Harbour Systems

Surveillance

Some of the areas in which improvements might be considered worthwhile are summarised in TABLE 5. They are a combination of present limitations and extended operational requirements. There is not space in this report to examine all of these possibilities. I will therefore concentrate on the collection of the basic raw data.

System Data

The major limitations concern environmental factors.

Effects from rain and sea state lead to clutter on radar displays. Such interference can have a serious effect on the ability of a radar operator to identify potential collision situations and to provide navigation information in time to assist the avoidance of such situations.

Our present work concentrates on two possibilities. First consider reduction of sea clutter effects. All present civil marine radars involve design compromises and this implies that the conventional design is not optimised for the reduction of sea clutter. In TABLE 6 some of these compromises are summarised. In the future a harbour system can be visualised to include a specific 'anti-clutter mode' that would incorporate many of the possible techniques eg digital processing using sea clutter statistics, and computer and display storage systems.

For reduction of rain clutter the use of circular polarisation is well known and systems are becoming available. What is most difficult to assess is the real value of such a facility. The problem is illustrated in FIGURES 2A and 2B. The use of the circular mode reduces the rain clutter amplitude and at the same time the received target echo, although to a lesser extent. The value of this mode is therefore a function of the probability distribution of ship sizes using the harbour, as well as the frequency of occurrence of rain. The mode will undoubtedly give improved performance with respect to larger ships but may fail to detect small targets at extreme range, and short range in the sea clutter zone, that would have been
<table>
<thead>
<tr>
<th>Function</th>
<th>Limitation or Extended Requirement</th>
<th>Possible Future Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Environmental</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rain</td>
<td></td>
<td>Circular Polarisation</td>
</tr>
<tr>
<td><strong>System Data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea State</td>
<td></td>
<td>Radar parameter design. Digital Processing, display storage.</td>
</tr>
<tr>
<td>Siting</td>
<td></td>
<td>Aerial design</td>
</tr>
<tr>
<td><strong>Data Display</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panoramic display of multiple radars.</td>
<td></td>
<td>Synthetic displays</td>
</tr>
<tr>
<td>Remote display operation</td>
<td></td>
<td>Daylight viewing</td>
</tr>
<tr>
<td>Reduction in manning and operator tasks.</td>
<td></td>
<td>Auto-tracking of selected targets.</td>
</tr>
<tr>
<td>Position monitoring of fixed objects.</td>
<td></td>
<td>Digital processing with auto-alarm.</td>
</tr>
<tr>
<td>Storage of traffic data.</td>
<td></td>
<td>Computer based systems.</td>
</tr>
<tr>
<td><strong>Data Processing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Data Transfer</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surveillance data at ship.</td>
<td></td>
<td>Pilot portable display and link unit.</td>
</tr>
<tr>
<td><strong>Total Harbour System Capability</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ship Identification</td>
<td></td>
<td>Secondary Radar</td>
</tr>
<tr>
<td>Position Fixing</td>
<td></td>
<td>Radar Triangulation</td>
</tr>
</tbody>
</table>
# TABLE 6

## SEA CLUTTER ON CIVIL MARINE RADARS

**SYSTEM PARAMETERS INVOLVING DESIGN COMPROMISES**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Present State</th>
<th>Possible Future System</th>
</tr>
</thead>
<tbody>
<tr>
<td>RANGESCALE</td>
<td>Display one at a time.</td>
<td>Second display with a close range scale.</td>
</tr>
<tr>
<td>PULSE LENGTH</td>
<td>Usually tied to scale.</td>
<td>Choice required.</td>
</tr>
<tr>
<td>BEAM WIDTH IN AZIMUTH</td>
<td>Fixed.</td>
<td>Wider beam for use with close range scales.</td>
</tr>
<tr>
<td>AERIAL HEIGHT</td>
<td>All round coverage requires high site.</td>
<td>Low aerial gives small clutter zone.</td>
</tr>
<tr>
<td>FREQUENCY OF TRANSMITTER</td>
<td>Majority of systems have X-band only</td>
<td>S-band can improve visibility of a target in sea clutter.</td>
</tr>
<tr>
<td>TARGET SIZE</td>
<td>Small boats, yachts and some buoys can present small targets.</td>
<td>All 'friendly' targets could provide echo enhancement, e.g., radar reflectors.</td>
</tr>
</tbody>
</table>
TARGET RAIN/CLUTTER RATIOS

**FIG 2A**

![Linear Polarisation Diagram](image)

**FIG 2B**

![Circular Polarisation Diagram](image)
detected in the linear mode.

The final environmental factor concerns the siting of radar aerial systems. This invariably involves compromises and is usually optimised for area coverage. Harbour Authorities can rarely control the design and size of other structures in the vicinity of their aerial systems. Radar 'ghosts' and generally unwanted echoes are a familiar sight on most harbour radar displays. Some palliatives are possible and can involve compromises in aerial design. The major problem will always remain the incompatibility of the requirement to detect and discriminate between small targets at long range and the resultant excessive system gain available at short range.

Guidance

In the review of present systems in this paper I mentioned the possibility of problems from multipath interference.

There are potential error sources in all guidance systems and system design is obviously directed towards minimising to the extent that the total cost constraints allow.

Error Mechanisms

When using bearing measurement techniques for a Channel Aid certain limitations appear to be inevitable.

Multipath Propagation

In the confined waters of a harbour approach channel, the probability of multipath propagation due to the reflection of microwave signals is high. Such reflectors might be jetties or wharfs, warehouse or cranes outside the channel or other vessels within or close to the channel.

Such reflected signals can interfere with the direct signal and produce variations in phase and amplitude which the receiving equipment will interpret as a change in bearing. Such bearing errors can be large. Their effect on a phase measuring equipment is found to be large compared to the accuracy required.

Glint

A Channel Aid may well require an offset accuracy of less than a few tens of feet. Such accuracies become difficult to achieve when the transmitting beacon is situated on a vessel of beam up to 200 ft. Multiple reflections from structures on the vessel, (derricks, vent pipes etc.) mean that the source of the radiation is not uniquely defined. Interference between such multiple sources can give rise to an effect known as 'Glint'. Offset error spikes of perhaps 220 feet may occasionally occur. In general errors are less than about half the ship's beam.
Working frequencies of portable units

A systematic error may occur if several different pilot portable units are required for each system. These will all nominally be identical but any slight differences in frequency between them may affect the calibration of shore mounted bearing measurement equipment. This error source is likely to be small for any reasonable variation in frequency between units.

Obscuration

In a busy, confined approach channel it may be possible for the Pilot portable unit and shore beacon to become optically obscured from each other, for example, a ship crossing the channel or tugs and other vessels in the channel. During such periods the received signal level will be reduced. Bearing measurement and possibly ranging systems may then become inoperative, or, before complete obscuration, may cause various effects (diffraction, interference etc) which produce erroneous readings.

This error source may be reduced by raising the height of the shore beacon so that the signal can pass over any obstruction, or possibly by restricting the movement of other traffic in the channel. (The latter is not feasible in the case of tugs if these were required to manoeuvre the guided vessel).

Effect of Errors on Operator Confidence

Whether bearing errors can render an approach aid unusable depends not only on how often the errors exist (which will be highly dependent on the particular geography of the approach channel and types of vessel using it) but also on how such errors effect the basic confidence of Pilots and Masters who will be using them, i.e. will they actually depend on the aid when conventional aids are inoperative? At this time it is impossible to answer this question since relevant studies have not been made. It would help, if erroneous indications could be reduced to a minimum or alternatively not displayed.

Minimisation or Recognition of Bearing Errors

There are many ways to approach the problem of minimising the effect of multipath error. There are methods of minimising the reflected signal power by either using circular polarisation which becomes depolarised on reflection or by adjusting the gain pattern of the receiving antenna. This latter technique requires that the gain over the channel be higher than outside, or that very narrow scanned beams be used. The narrow beam solution has been shown to give little advantage. Gain compensation is usually unnecessary if the range resolution of the equipment is good enough.
Minimisation by Range Resolution

When a signal is received both directly and after reflection, the reflected signal always arrives after the direct, the path length having been increased. Consider the situation of FIGURE 3 where a transmitter, T, is separated from a receiver R, by the distance D. Now if a reflecting surface, S, is positioned at a distance X, normal to the line T-R, the extra path length between T and R is Y. It can be shown for a given Y, the locus of the point S is an ellipse. If Y is now the range resolution of the equipment it can be seen that reflections from outside this ellipse will not be detected at R. Within the range X however, reflected signals will be received and bearing errors occur.

With an angle measuring system the value of Y will depend on the time required at R for the bearing to be measured.

It can be shown that for X to be a maximum (the minor axis of the ellipse)

\[
X = \frac{Y^2 + 2DY}{4}
\]

For a phase measuring equipment the time required for bearing measurement is about 100 nS, which means that Y is about 100 feet. This gives a maximum value of X of over 700 feet at a range of 20,000 feet (3.3 nautical miles). Although this is large it may still be within the approach channel limits. The system would then be immune to reflections outside the channel. At closer range the situation is further improved (for D = 1,000 feet X max = 115 feet). Bearing errors due to multipath would then only be possible from objects within the channel i.e. other shipping or large buoys.

In practice the situation is still further improved since the angular coverage of the transmitter and receiver is usually restricted to looking along the channel. Reflections from the sides and back of aerials can then be much reduced. This assumes the use of a phase measuring (interferometer) system. If an amplitude comparison system were used, the sampling frequency would need to be in excess of 10 MHz. For civil marine applications such a technique might prove expensive.

Error Recognition by signal comparison

Various techniques can be used to minimise the likelihood of multipath error. Such methods cannot entirely protect a system, so some method of error recognition is needed to prevent false information being displayed.

Some of the techniques available for error recognition are:
Computer Tracking

If the occurrence of error is rare, continuously stored historical data can be compared with that received later. Any variations which cannot be accounted for by movement of the vessel in the intervening time period would indicate some form of error.

The advantage of such a system is that error in range, bearing and speed can be recognised. The disadvantages however are significant. Such a system would require computing and storage facilities which might prove expensive for civil marine applications. The probability of error would require to be low since a comparison track would need to be generated.

Frequency or Amplitude Modulation

If either the frequency or amplitude of the transmitted signal is varied in a known way, the variation of the other received parameter may indicate multipath conditions i.e. in a phase measuring system, the amplitude of the received signal is not important, (as long as it is above the receiver threshold). However, in the presence of multipath, amplitude modulation may result in phase variations, at the same frequency as the initial amplitude variation. Such a condition would indicate the occurrence of multipath. The results would be similar for an amplitude measuring system and frequency modulation. In practice this would not be possible since with harbour systems the use of a continuous band of frequencies might interfere with other equipment.

Modulation techniques would degrade the range performance of guidance aids since time would be required to know that the received signal was varying (i.e. for 100 μs resolution the amplitude would need to be modulated at greater than 10 MHz).

Instantaneous signal comparison

The ratio of the direct to reflected power at the receiver determines the magnitude of a multipath bearing error for a particular system. These reflections may be from transmitted signals at the sea surface (Lloyds Mirror). This effect varies the amplitude of the transmitted signal in the vertical plane, producing deep fades at various heights above the sea. The normal dynamic range of receivers would need to be extended to cope with such fades, so shore equipments require to be duplicated to produce vertical space diversity. This then provides a simple method whereby the existence of multipath can be detected.

In general the vertical variation in amplitude of the direct and reflected signals will be different due to the different propagation paths. The amplitude ratios of direct and reflected signals will be different. The bearing measured at each of the equipments will then indicate different angles.
On comparison of measured angles any difference would indicate the presence of multipath. Bearing information would then be treated as suspect and not transmitted to the portable unit.

When one of the shore units is suffering a deep fade and becomes inoperative, a check mechanism is essential. It might be better not to transmit a bearing from the now single system since its reading may be in error.

These techniques have been used with success with the channel aid at Milford Haven.

An example of the offset accuracy and multipath problems is shown in FIGURE 4.

The use and problems concerning channel guidance aids have been reviewed. To what extent such systems are fitted in the future will depend not only on the ability to give continuously accurate information but also on the total cost of the system. At present these appear to be mutually exclusive in that cheap and unsophisticated systems are likely to be susceptible to uncontrolled errors. It would appear difficult to specify a general solution. In all probability each system will require to be tailored to fit a particular harbour geography.

4. Conclusions

Present systems have been reviewed and some limitations and possible future requirements identified. Some of the possible future techniques have been discussed together with an indication of the likely complexity, time scale and cost/performance benefit.
RANGE/BEARING SYSTEM
IMPROVEMENT WITH SYSTEM MODIFICATION

FIG. 4

Modified Unit
Unmodified Unit
In stepwise analysis any difference would indicate the presence of a contribution. Having information would then be treated as suspect and not associated to the particular unit.

Many of the above units are occurring in deeper and therefore less visible. It might be interesting to transmit a signal from the lower levels of these units since the reading may be in question.

These techniques have been applied and simulated to the original data at which these.

An example of the -test accuracy and reliability problems is shown in FIGURE 4.1.

The use of the arctic-boreal transitional regions which have been reviewed. Despite the test that systems are applied in the region will depend not only on the ability to give sufficiently accurate information but also on the root of the data. The present data appears to be actually related to the data and, once determined, can be linked to the original data and the new root.

By doing this different buildings requiring techniques will result in a closer to the original data and root.

Symmetry has been maintained and an accurate sense and potential have been identified. Most of the possible techniques suggested have been aligned together with an indication of the new root. This paper was written.
Education and training of personnel involved in traffic management
Education and training of personnel involved in traffic management.
Summary

A brief discussion is presented of some aspects of the performance of the human operators being a part of each marine traffic guidance system. Some basic concepts of the study of the human performance are introduced, coming from experimental psychology. Although the views expressed in this paper mainly concern the men directly involved in controlling the ships, the approach is applicable to all people playing a role in the systems concerned. The paper stresses the importance and usefulness of the concepts skill, acquisition and measurement of skill and simulation as a tool to study these and other factors, contributing to the optimum performance of the marine traffic system.

1. Introduction

A critical consideration of all aspects related to the design, the introduction and the operation of Marine Traffic Systems will always include the role of the human beings who play a part in one or more of the subsystems forming the traffic guidance system. As it can be assumed that already in the design stage of the system it will be decided which tasks are to be allocated to human beings and which to machines and automated control devices, then also an adequate and specific training program will be available to prepare operators for the tasks assigned to them. What type of capabilities or skills will be required by the human operators being elements of the system depends on the task to perform. In this paper only the task of the man controlling and handling the ship is considered. This is in no way to suggest some hierarchy of the people or the elements of a marine traffic system, but rather due to the restrictions in the competence of the authors.

The approach chosen for this paper is an introduction and a discussion of some concepts related to the human performance in the handling of ships, whether or not guided by a supervisory or advising traffic control system. Rather than discussing these aspects from the viewpoint of experienced shiphandlers, ship owners or harbour authorities, we prefer an approach from a

*Netherlands Ship Model Basin*
psychological point of view. Although it is hardly known, the experimental psychology has generated an overwhelming amount of data about the possibilities, the restrictions and the specific characteristics of men performing complex tasks in technical and social systems. This branch of psychology, also indicated by "the study of human performance", analyses the processes involved in skilled performance and covers the acquisition of the skills (motor-skills and mental skills) as well as the establishment of quantitative measures of skilled performance (1). The next chapters deal with the skilled performance and its measurement as far as the ship handling tasks are concerned. However, the general approach and the same basic concepts ("skills", "task load") apply as well to the behaviour of other operators in the traffic guidance systems under study.

2. Characteristics of skills

It is obvious that a man involved in such complicated processes as carrying out manoeuvres with a ship, must have a high degree of training on several tasks. In general, operators of advanced technical systems meet specific problems of a perceptual and decisive type. To handle these problems they are trained in particular skills. These skills do possess three characteristics (2):

1. They consist essentially of the development of an organized and coordinated activity in relation to an object or a situation.
2. They are learnt, in that the understanding of the object or situation and the form of the action are built gradually in the course of repeated experience.
3. They are serial, in the sense that within the overall pattern of the skill many different processes or actions are arranged and coordinated in a temporal sequence.

Within any skilled performance these characteristics are closely bound together. Therefore a performance can only be called a skill when all three characteristics are met. For instance, knowledge about to launch a life-boat is not regarded as a skill if no repeated experience in doing it has been a part of the acquisition of the knowledge. Special care must be taken in the distinction between manual and mental skill. In the case of the launching of the life-boat we consider the skill as a manual one, because the overt actions form an essential part of the activity. Without this overt activity the purpose of the skill as a whole would not be there. It is easy to understand, however, that without any mental processes at all, backing up these overt actions, the launching would end up in a disaster. In mental skills, overt actions are only part of a way to express the skill. The only overt action in multiplying five prime numbers within two seconds is the writing down of the answer. This writing being a manual skill in itself!
The conclusion may be that there is no sharp distinction between what is a manual and what is a mental skill. Every overt or covert action may be somewhere between these limits. Equally understandable is the fact that every action by a human can be placed somewhere on the continuum between unskilled and skilled. If we find ourselves taking action, some distance away from the unskilled pole, deliberately working up to the skilled pole we are acquiring a skill. The problem in this process of acquisition is to determine at which point the action really is a skill. To solve this problem one has to measure performance. The problem of measurement of performance can be approached by the study of information processing by man. One receives information from his environment, codes this information into patterns of neural excitation and stores them. The result of this process is a pattern of behaviour characterized by the received information and the individual internal handling of it.

3. Organisation of performance on a ship's bridge

If we look to the kinds of action undertaken to control a ship we can basically discern performance on three hierarchical levels. They are in a reverse order:
1. the manipulation of the wheel to keep the course,
2. the decision as to which course should be followed, and
3. the level at which is decided which sequence of course should be followed, or else: which manoeuvre should be performed.

The wheel manipulation task is mainly performed by the helmsman. His skill is related directly to the object "ship". The desired course is known to him, and by reacting to information about the actual course given by appropriate instruments he must be able to minimize the occurring differences. This can be illustrated by Fig. 1.

Acquisition of this skill is relatively simple. Apparently a helmsman grows into this function by simply doing the job. From a psychological point of view, however, it is advisable to provide him with information about "his part" of the ship. For instance, knowledge of the consequences of his actions on the mechanics of the steering machine will give a better interaction between man and job.

The decision about which course should be followed at a given time is usually made by the master or the pilot. The entire process of making such a decision, from the acquisition of all sorts of relevant information and the rejection of irrelevant information to the ordering of the course to the helmsman is a skill he has to master. The complexity of this can be learned from Fig. 2.

An interesting point is that this task is to a high degree an information integration task and not merely an information processing task (3). The relation of this skill is not only to the object of the ship itself but also to the situation
Note to figures 1 and 2: The question whether the steering task of the helmsman is a compensatory or pursuit tracking task, depends on the way in which information about the ship's movements is given: by an instrument that displays the difference between
Fig. 2. Information flow in controlling a ship

External distortions: weather, sea condition

Configuration under observation

Internal information

Other orders

Ship

Master or pilot

Desired course

Helmsman

Rudder signal

Actual course

External information

Position of ship

Other traffic

Hydrographical information

Shore based guidance

the desired and actual course (Fig. 1) or by an instrument (Fig. 2) respectively.
Fig. 3. Information flow in executing a manoeuvre (Adapted from [3])

Master or pilot

Deflection of the manoeuvre

Desired course

Determination of the desired course in order to compensate for the deflection of the manoeuvre

Deflection of the course

Determination of the compensation for the deflection of the desired course

Control signals

Ship

Inner-loop

Outer-loop

Actual manoeuvre

Actual course
in which the ship is at the moment of his decision. The master or pilot, has access to two kinds of information in respect to the development of his skill. The first is mainly his theoretical knowledge about manoeuvring and how to make decisions about that. This knowledge he learned at his naval-college and he has up-dated it ever since. This is his "stored" knowledge. The second kind of information is his recent experience of the behaviour of the ship under known circumstances. In this example it becomes apparent that separate actions, most of them mental, line up to a chronological sequence. In this sequence loops may occur, when new information is introduced instantaneously, or even when mistakes in the course of reasoning are perceived. In a sense the same actions are performed at the third level of action in deciding which manoeuvre will be selected. The difference can be understood by explaining Fig. 3. In executing a manoeuvre the course of the ship may have to change several times. When the master has decided to make a manoeuvre he will determine a course-sequence. The inner-loop in Fig. 3 is, in this case, a summary of Fig. 2, and compensates for deflections from one course during the manoeuvre. The outer-loop transports the same information. This information is used, however, to compensate for deflections in the sequence of courses. For these tasks, the skills a pilot has to control are roughly the same as for the master. The content of the "stored" information a pilot brings in is somewhat different. The pilot's knowledge about the ship-behaviour characteristics is not as detailed as the master's. On the other hand the experience the pilot has with external influences in a defined region, including information he gets from eventually present shore based guidance systems, is more specific.

4. Measurement of performance

By now it will be obvious that in the very complex process of controlling a ship, the skillfulness of the people involved will have an important influence on the performance of the total system. It is also clear that the restrictions placed upon the freedom of decision for the master and pilot are highly dependent on external factors. The problem in an evaluation of these kinds of skills is the method of measurement. The success of an analysis of skills depends upon the method chosen to measure performance. The measure should in an optimal way characterize the input-output relations of the system-operator, i.e. the helsman, the master or the pilot. To obtain this measurement one can select some criteria (1). The first is that the obtained measure captures the degree to which the output reflects the input. In the case of the master choosing a course it was stated before that his task was one of information integration. The measure taken to account for the skillfulness in executing this task will have to be sensitive for the quality
of this integration.

The second criterion is that the method of measurement should be appropriate to three types of tasks: discrete, serial and continuous. The steering of a ship is a matter of discrete course directives as an output of the master, and an input for the helmsman. However, the reading of the rate of turn indicator and the rudder angle indicator is a serial process. A continuous task on the bridge of a ship can be the observation of the radar for a longer time. A measure for the total skill of manoeuvring has to fit these different kinds of tasks.

The third criterion is that the measure should be sensitive to the accuracy of the responses made by the subject. When a course is given to the helmsman he can react in such a way that on the average the ship holds that course. He can also aim at the exact course and steer continuously. The accuracy of the carrying out of the task is different, the result still being the same.

Next there should be sensitivity to time in the measure. Skills depend most on timing of a series of actions. Besides that, the time a man takes to perform a task will influence the accuracy, that in some cases may have to be corrected with regard to the available time.

Finally, if the measures are to be used in motor as well as in language skills, they have to be rather general. In controlling a ship, this criterion is less important, because no device is available for steering with vocal cords.

Another class of criteria that have to be met, are related to variables that a high degree constitute man's behaviour (4). They are:

1. Parameters of surrounding, such as noise, illumination, vibration, temperature.
2. Personal variables, such as age, experience, fitness.
3. Task-variables, such as display characteristics, dynamics of disturbances.
4. Procedural variables, for example the instructions about how to execute a task.

An optimal measure to this class of variables, either tries to keep them constant over the period of measurement, or allow them to vary in a controlled way. Even in laboratory situations insensitivity is very unrealistic and almost impossible to achieve. To keep two, sometimes three of these variables constant is an accepted procedure in research in psychology and human engineering. Most types of statistical methods can account for the controlled variation of variables not held constant.

There will be no single measure that is able to meet all of these criteria. One type of measure is based on the rate of information transmission of the operator (5). Other types are confounded with physiological and psychological concepts (6). One of these concepts is "stress" often used together with "arousal", to describe the general state in which the operator is as a consequence of the execution of his task (7, 8).
5. A secondary task as a measure of skill acquisition

In summary, to measure a skill is to measure performance, one way or another, on a well-defined task. However, in executing a relatively simple task, or in controlling a slow-reacting system like a ship, this measurement can be problematic. When a man is working underneath his capacities he is not likely to make errors, or to hurry in executing the task. Measurement of performance under these circumstances will not reflect the progression man makes in developing a skill. A method to measure this progression in spite of the restrictions is to give a "secondary task" to the man. The principle of this procedure is illustrated in Fig. 4. (9).

![Diagram showing the use of a secondary task to measure primary task differences.](image)

**Fig. 4** Illustration of the use of a second task to measure primary task differences.

An example of such a secondary task is the taskload test used by the authors, which will be described in detail in the next chapter.

Measuring the progress in "quality" of the execution of a manoeuvre in reality is almost impossible because of the large amount of varying conditions under which successive manoeuvres are made. Therefore the use of a simulator offers great advantages. In creating a situation in which irrelevant distortions of the ship's behaviour and of the environmental situation on the bridge are ruled out, the demand of reproducible measurement can be met. Namely, to obtain a method with predictive value it is necessary to rely upon a number of observations made under exactly the same circumstances, which should be spread over as much different operators as possible, to account for the variability between men.
6. Observations on the NSMB manoeuvring simulator

The instrument used at the Netherlands Ship Model Basin at Wageningen, the Netherlands, is a full scale, real-time manoeuvring simulator (Fig. 5). This simulator makes it possible to study a wide variety of problems related to manoeuvring with all kinds of ships, under circumstances that can be controlled strictly. Although the main objectives in studies, carried out in the past were the identification and solution of problems related to the behaviour of the man-and-ship-system as a whole, some effort has been made to explore the behaviour of the man on the ship-system.

Fig. 5 Schematic view of the N.S.M.B. manoeuvring simulator.

The first attempt made in this direction was to define a measure of task-load, to obtain information about the acquisition of skill in controlling a ship. In fact, the measures of task-load obtained this way have been used as a reference for task-load in the study of manoeuvring problems, in which man is not necessarily the sole object of interest.

The procedure is as follows: on the bridge of the simulator four lamps and a push-button are placed (Fig. 6). In the course of a manoeuvre the lights flash-on in a random sequence, and have to be extinguished by the subject by pushing the button as quick as possible. The instruction to the subject is always to carry out the manoeuvre in the first place. It is told to him that the accuracy and speed with which the button is pushed does not interfere with the quality of the manoeuvre.

The results of these tasks are as shown in Fig. 7.
Fig. 6 Plan of the first bridge with the arrangement of reaction-lights and push button.

Fig. 7 Mean reaction time in seconds as a function of the first and last manoeuvre of eight subjects. The number of missed reactions as a percentage of the total number of lights, for two subjects.
The subjects were executing a relatively simple although not common manoeuvre, in which no errors were detected. The down-fall of the reaction time and the number of missed lights, i.e. lights on which no reaction has been given, in the course of successive manoeuvres indicate that there has been a substantial amount of skill acquisition.

In comparison to the principle in Fig. 4 it can be concluded that while the reaction-time on the secondary task, i.e. the lamp test, goes down, the capacity available for this task increases. An increase in this capacity is a result of a decrease in the capacity needed for the primary task. In this way the progression of the acquisition of skill can easily be demonstrated.

7. Conclusions

As a result of the considerations given above, the authors like to stress the importance of the human aspects of any marine traffic (guidance) system. The following statements, however, shall be considered starting points of a fruitful discussion, rather than the elements of an irrefutable truth.

1. The successfulness of a marine traffic (guidance) system depends not only on an advanced technological effort, but also on a deliberately bringing in of the human operators (ship and shore based), who can be considered playing a role in the system.
2. The proper allocation and structuring of tasks to be performed either by machines or men, requires extensive knowledge of the possibilities and restrictions inherent to the human being.
3. A fruitful approach to these problems goes from experimental psychology, that enables study and measuring of human performance, using among others concepts like skill, skilled performance and acquisition of skill.
4. Simulation of the various parts of a traffic system or its elements, is an efficient tool for different reasons:
   a. The elements of the system can be tested in the preconstruction stage already.
   b. Design alternatives can be studied in order to search the optimum system design.
   c. Measurements of system performance can be established in a controlled way, without contamination from uncontrolled sources as is the case in the real life situation.
   d. The allocation and structuring of the tasks to be performed by men and machines can be facilitated by proper research on general purpose simulators.
   e. The human operators which become part of the system can be trained to achieve a skilled level of performance, before the system is put in operation.
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Miscellaneous subjects related to marine traffic systems
SEA TRAFFIC RECORDINGS FROM THE ENGLISH CHANNEL
UP TO THE PERSIAN GULF

K. H. Kwik
W. Stecher

Summary

To gain basic data on the way to more safety in navigation the radar picture aboard a ship on her voyage from Europe to the Persian Gulf and back was filmed. From this recording data as passing distances, traffic densities, encounter rates, courses and speeds of encountering vessels along the ship's route can be obtained. This paper gives a description of the method and presents first results of the evaluation.

1. Introduction

While the number of ships over 500 g.r.t. totally lost mainly as a result of navigational or manoeuvring failures on an average has remained approximately constant in the last two decades, the losses by tonnage have an increasing tendency, see figure 1. This means that more and more bigger ships are involved in casualties which can be classified as "collisions". The results of such casualties are also getting more and more serious. In addition, casualties leading to partial losses can be just as serious. Therefore, several measures have been taken with the aim of protecting ships from collisions.

However, each far-reaching measure should be founded on the results of a thorough analysis of the real traffic, if possible unwanted results are to be

1 A joint paper from the Sonderforschungsbereich 98 "Schiffstechnik und Schiffbau" at the Institut für Schiffbau, Hamburg, and the Verband Deutscher Reeder, Hamburg.

2 Institut für Schiffbau der Universität Hamburg, Hamburg, Germany.

3 Verband Deutscher Reeder, Hamburg, Germany.
avoided. Therapeutic measures should always be preceded by a thorough diagnosis! This seems to be disregarded sometimes, as far as measures on safety of traffic at sea and the laws governing the traffic are concerned. Rules have been issued, which perhaps would be drawn up differently, if the ins and outs were known better. Moreover, it is desirable to know, which safety exists and which safety is strived for. Deliberations like this induced us to carry out a program of traffic recording which in this scope up to now is apparently without parallel, and which is to give the facts to support a thorough analysis of the conditions prevailing at sea as well as to enable the safety against collisions to be estimated.

To obtain accurate basic data on a large scale, the radar picture received aboard a ship on her voyage from the German Bight via Cape of Good Hope to the Persian Gulf and back was filmed. Thus the total encountered traffic within a radius of 24 nautical miles was recorded and each situation, considering geographical co-ordinates as well as precise time, can be reconstructed. The recordings are to give information about data such as passing distances, traffic densities, traffic flows, encounter rates and behaviour of ships on the route travelled by the ship.
The results of a research program such as ours could and should be used wherever new measures with a bearing on safety at sea are discussed and relevant decisions taken. This would enable a treatment of any ailment of the patient with the minimum but most effective dose of medicine, in the fields of training bridge personnel and watchkeeping as well as in those of ship and equipment design and of their - and administrations' - joint operation at sea.

The concern of the German Shipowners' Association to increase safety in navigation and the effort of the research project "Safety of Ships against Collisions" of the "Sonderforschungsbereich 98" to calculate the collision rate have led to this joint paper.

2. Description of the method

By recording the radar picture of a sailing ship we wished to obtain as extensive as possible material from many parts of the earth. Therefore, our research program differs from surveys of similar kind which have been done from stationary points, mostly Coastguard or Pilot Stations, and which only cover restricted areas. Of course our method is less suited, if certain areas were to be observed continuously. This could be done, if the ship were instructed to stop.

Only limited funds were available when this research program was proposed. So from the very beginning the point of cost-effectiveness was predominant. Inevitably some sophisticated techniques had to be disregarded, as e.g. use of auxiliary means such as described in [1] for perfect ship identification or use of magnetic tape recording together with some far-reaching questions of the researchers which could only be answered if numerous additional personnel would be employed. Availability was another point of interest which had to be applied to suitable ships with suitable radar as well as to the recording equipment and material and to a co-operative staff of master and navigating officers.

Laboratory and field trials with Super-8 semi-professional camera equipment and film proved that the picture on the PPI of a normal navigational ship's radar

\[ ^4 \text{Numbers in brackets designate References at end of paper.} \]
could be recorded this way. The minimum exposure was found to be equal to the duration of one antenna sweep with the diaphragm setting \( f = 2.8 \), using daylight colour film with a sensitivity of 25 ASA. The diaphragm setting was later changed to \( f = 4.0 \) and the shutter time to two antenna sweeps corresponding to about 5 seconds in order to compensate for occasional weak echo paintings. The camera finally chosen was a standard model of German manufacture with built-in quick motion capacities. The shutter was activated by an electronic trigger unit with a servo produced by the same manufacturer. Electric energy was taken from the ship's mains by means of a transformer/rectifier unit supplying a stabilized 7.5 V dc output. The film used was a daylight colour movie film in super 8 cassettes\(^5\). A temporary steel girder was screwed under the ceiling of the wheelhouse. A swivelling head was fixed to it and supported the camera. The curtains were drawn tight to eliminate stray light. The hardware was ready to be operated by the ship's navigating staff.

Before Captain Bachor took his ship to sea he was asked to keep a scrap log on the bridge to record as many encounters with other vessels as possible giving all information he could about identity, type, size, nationality and other details of the ships together with time, position and particular circumstances of the situation. It must be gratefully acknowledged that he did a much more precise and complete job than could be really expected.

3. Selection of a suitable vessel

The selection of a suitable vessel from about 900 member ships of the German Shipowners' Association turned out to be not as easy as expected. Finally the ULCC "LAGENA" of the Deutsche Shell Tanker GmbH was chosen for the first phase. She complied with all essential requests. First of all she was immediately available in her builders' yard to take the equipment on board and to have her navigators briefed about the means and the objectives of the scheme. Secondly she was scheduled for a voyage of more than 20,000 nautical miles to the Persian Gulf and back to the North Sea. She was big enough to provide a very solid plat-

\(^5\) Product names will be supplied by the authors on request to enable any interested person or institution to apply the method without delay.
form for the equipment and a radar antenna with sufficient height over sea level. She carried two navigational radars of which one could be left to the unobstructed use of her command while the other was committed to the recording scheme. Finally she had a doppler sonar log which could be used to indicate and record own ship's speed continuously while own ship's course would be indicated by the heading marker of the stabilized radar picture. A dial showing the longitudinal speed component was thus mounted together with a clock on top of the radar display unit adjacent to the PPI. Unfortunately this was a partial failure because the camera's field of vision was too small to include all of these additional displays and because the appropriate regulation of display illumination had not yet been adequately solved.

Further details of the ship are given in appendix 1 of this paper. Particular attention is directed to the manoeuvring characteristics which are impressively similar to those of vessels with one hundredth of LAGENA's size.

4. Investigated area

The TT "LAGENA" followed the traditional oil route via Cape of Good Hope on her normal voyage from Western Europe to the Persian Gulf, see figure 2. After leaving Hamburg she took the deep water way westward from the German Bight where she had adjusted her compass and RDF equipment, passed the Dover Strait in the appropriate lane and continued through the Casquets and Ouessant Traffic Separation Schemes to the Biscay. Cape Finisterre was left at a considerable passing distance to port. She passed along the Canary Islands and went on to Capetown on the customary direct route. She sailed round Cape of Good Hope, through the Moçambique Channel to the Strait of Hormuz and to her various loading ports in the Persian Gulf. On the homeward voyage nearly the same way in opposite direction was taken. Off the South African east coast she had temporarily to heave to because winds up to Beaufort force 12 with very heavy sea were encountered. After having passed the Biscay she proceeded to Lyme Bay where she met the 120,000 tdw "NATICINA" to lighten her. With the remainder of her cargo she went to the appropriate lane at the south side of the Channel and passed with severely restricted visibility through the Dover Strait and the deep water route at the north of the Sandetté Bank until she finally moored at her discharging berth at Europoort.
The speed made by the ship on an average has been less than the designed ship's service speed (about 12 knots on the high seas). On this voyage the ship has been under way for the total of 78 days, during which traffic recordings were made. A comparison with for instance [2] gives us to expect that our ship has been sailing through one of the densest shipping lanes of the world.

Figure 2: Route of the ship

The investigated area corresponds with that area swept by the radar during the voyage of the ship. The radar range switched on was 24 nautical miles throughout. Taking the distance from Rotterdam to Bushire to be about 11,000 miles, one gets an area of 1.81 million square kilometres for one single voyage. This is the area investigated on one voyage and corresponds to about 0.5 per cent of the surface of the earth covered by water.

5. Analysis of encountered traffic

Inputs

The ship's radar has been working in the relative motion mode, with the ship's head upward on the outward voyage and north up on the homeward voyage. Thus all relative movements within a range of 24 nautical miles around own ship during her entire voyage have been recorded. Passing distances to own ship can be obtained immediately from the movie, while the movements of the blips give the speeds of other vessels.
relative to own ship and their directions. These relative velocities together with own ship's data of motion are to give the desired true quantities. Arrangements were also made to film own ship's speed log and, in the ship's head upward mode, a course indicator at the same time. Unfortunately, as mentioned before, some technical difficulties upset our intentions. Thus, to obtain own ship's data of motion we had to refer to the captain's entries at corresponding times. These entries concerning geographical coordinates of the ship were made specially for this research program at very short time intervals.

Calculations

Everyone engaged in navigation knows how to estimate course and distance, given successively the positions of the ship. We used the mid latitude method for determining own ship's data of motion. For the sake of clearness the method is given in appendix 2. The method is considered accurate enough, as the differences of the longitudes and latitudes, respectively, at every successive entry were less than one degree. Own ship's speed is found by dividing the estimated distance by the time the ship took to travel the distance. It was smoothed graphically, should it have jumps for no obvious reason. The same was also done with the estimated course.

With own ship's vectorial velocity and relative velocities of other ships known, true courses and speeds of other ships can be calculated. The method is given in appendix 3. It should be pointed out that the method is somewhat different from that used aboard ship to estimate target's speed and course. There the inputs are usually, besides own ship's data of motion, relative bearings and distances at relatively short time intervals at an early stage of the encounter. The purpose is to predict possible future constellations of ships. We have, however, relative paths actually travelled by the ships within the range of the radar recorded on the film. Passing distances, directions of movements relative to own ship's course and times taken by the ships to travel certain distances can be taken immediately from the recordings.

We speak of an encounter, whenever at passing the distance is less than or equal to a certain amount. This is equivalent to saying that an encounter occurs, whenever another ship enters a certain area around own ship irrespective of her course. To simplify matters let the area be circular with own ship in the centre. The radius of the circle equals the passing
distance, beyond which an encounter is left out of consideration. Thus the number of encounters is simply the number of ships entering the radar screen at corresponding range. The encounter rate, which is defined as number of encounters per ship and unit time, is obviously easily calculable.

Traffic density, i.e. number of ships per unit area, can generally be found by counting the number of ships contained in a specified area at one moment. As we will see later on, however, in many areas of own ship's route encountered traffic is almost only composed of ships steering in the opposite direction. If it can be assumed that ships are equally likely distributed within a certain range, then in this case traffic density can also be calculated as follows:

$$\text{traffic density} = \frac{\text{encounter rate}}{2r \left( V_0 + E[V_a] \right)}$$

Here, $r$ denotes the range, within which encounters are considered, $V$ denotes own ship's speed and $E[V_a]$ denotes the expected value of other ships' speeds. The method is exact, as long as oncoming traffic only is considered [3].

Some results

Some results from the recordings of the outward voyage only can be given in the following because of the shortness of time available for preparing this report. Table 1 shows number and type of encounters during the voyage from just off Texel up to Khark in the Persian Gulf. The radius, within which encounters are considered, in this example is 24 nautical miles, i.e. equal to the full radar range. The average speed of the ship is 12 knots.

Table 1: Number and type of encounters

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>English Channel</th>
<th>Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head-on meeting</td>
<td>833</td>
<td>135</td>
<td>698</td>
</tr>
<tr>
<td>Crossing</td>
<td>88</td>
<td>57</td>
<td>31</td>
</tr>
<tr>
<td>Overtaking</td>
<td>71</td>
<td>7</td>
<td>64</td>
</tr>
<tr>
<td>Total number of</td>
<td>992</td>
<td>199</td>
<td>793</td>
</tr>
<tr>
<td>encounters</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The table shows that a vast majority of encounters (about 84 per cent) is composed of ships steering reciprocal or near reciprocal courses. Without the English Channel area, where crossing traffic is high in proportion, the percental portion of head-on meetings is even higher (about 88 per cent). This of
course is due to the fact that our ship was sailing mainly parallel with shipping routes. Considering the entire voyage with the ship being under way for a period of 40 days, it follows that the number of encounters per hour is 1.03. It is interesting to note that own ship has altered course to avoid close quarters situation a total of 15 times, 13 times to starboard and twice to port. The highest course alteration thereby observed was 30 degrees. Surely it is mere accident that own ship has been avoided by other ships 15 times also!

The distribution of passing distances experienced at the voyage, considering only ships steering in opposite direction within a 16-miles-range, is shown in figure 3. The number of head-on meetings within this range was 780, about two thirds of the encountered ships passed at port. It is striking that a great number of encounters took place with relatively small passing distances, even on the high seas, without any avoiding action being taken. The figure shows that

![Figure 3](chart.png)

**Figure 3**: Cumulative distribution of passing distances with vessels steering on reciprocal course (only passing distances less than or equal to 16 nautical miles considered)
18 per cent of the ships passing port and 16 per cent of the ships passing starboard did so at a distance equal to or less than 2 miles. Nearly 50 per cent of the encountered ships passed at a distance equal to or less than 6 miles.

Table 2: Encounter rates at some selected areas

<table>
<thead>
<tr>
<th>Area</th>
<th>own ship's speed in knots</th>
<th>encounters per hour</th>
<th>head-on meetings in per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>English Channel</td>
<td>15.3</td>
<td>8.29</td>
<td>67.8</td>
</tr>
<tr>
<td>Lisbon-Casablanca</td>
<td>14.8</td>
<td>2.38</td>
<td>91.2</td>
</tr>
<tr>
<td>Canary Islands-Guinea</td>
<td>11.9</td>
<td>0.93</td>
<td>94.4</td>
</tr>
<tr>
<td>Liberia-South West Africa</td>
<td>11.4</td>
<td>0.67</td>
<td>88.3</td>
</tr>
<tr>
<td>Off Capetown</td>
<td>11.0</td>
<td>1.25</td>
<td>100.0</td>
</tr>
<tr>
<td>Port Elizabeth-Mogadishu</td>
<td>12.4</td>
<td>0.09</td>
<td>72.7</td>
</tr>
<tr>
<td>Persian Gulf</td>
<td>13.6</td>
<td>2.08</td>
<td>84.0</td>
</tr>
</tbody>
</table>

Table 2 shows encounter rates at some selected areas. The radius of consideration here is 24 miles again. The figures give a picture of the traffic in several areas. The daily number of encounters in each of the large regions between Canary Islands and Guinea, Liberia and South West Africa, and between Port Elizabeth and Mogadishu is almost constant, so that each of these regions can be considered as one area. The encounter rate in the English Channel is roughly 12 times as great as on the route Liberia-South West Africa and roughly 92 times as great as on the route Port Elizabeth-Mogadishu. It can be said that usually several ships entered the radar range each day. It only happened twice that not a single ship was observed on the radar screen for more than 24 hours running (Indian Ocean).

It appeared that in some areas passing distances are uniformly distributed up to a range of 16 miles. This means that in these areas ships are equally likely distributed within the stated range. Figure 4 shows speed distributions at some of these areas. It is evident that in most cases speed probability density can be approximated by a single-peaked function. (The discrete values at very low speed are due to groups of fishing vessels.) Traffic densities of these areas together with that of Dover Strait are given in table 3. The figure for the Dover Strait was found by counting the number of ships at one moment (14 June 1975, 4 o'clock p.m.) including crossing and overtaking vessels. The figures for the other areas were calculated according to the formula given some pages
Figure 4: Cumulative speed distributions of ships steering on reciprocal course in some areas (only ships passing at a distance equal to or less than 16 nautical miles considered)

Table 3: Traffic densities at some selected areas

<table>
<thead>
<tr>
<th>Area</th>
<th>Ships per square nautical mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dover Strait</td>
<td>0.14</td>
</tr>
<tr>
<td>off Gibraltar</td>
<td>0.0027</td>
</tr>
<tr>
<td>off Nouadhibou (Spanish Sahara)</td>
<td>0.0012</td>
</tr>
<tr>
<td>Liberia-South West Africa</td>
<td>0.0008</td>
</tr>
<tr>
<td>off Capetown</td>
<td>0.0018</td>
</tr>
</tbody>
</table>

before, with a 10 per cent addition to include crossing and overtaking vessels. The densities in most cases are very low, because usually ships are spread over a wide area on the open sea, even on shipping
There are only few places on our ship's route, where crossing traffic constitutes an essential part of the total traffic. One of these places is clearly the Dover Strait. Course and speed distribution of vessels in this strait at one moment is shown in table 4.

Table 4: Course and speed distribution in the Dover Strait

<table>
<thead>
<tr>
<th>Course in degrees</th>
<th>Speed in knots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-4</td>
</tr>
<tr>
<td>0-30</td>
<td>0.016</td>
</tr>
<tr>
<td>30-60</td>
<td>0.016</td>
</tr>
<tr>
<td>60-90</td>
<td></td>
</tr>
<tr>
<td>90-120</td>
<td></td>
</tr>
<tr>
<td>120-150</td>
<td>0.016</td>
</tr>
<tr>
<td>150-180</td>
<td></td>
</tr>
<tr>
<td>180-210</td>
<td></td>
</tr>
<tr>
<td>210-240</td>
<td>0.016</td>
</tr>
<tr>
<td>240-270</td>
<td></td>
</tr>
<tr>
<td>270-300</td>
<td>0.016</td>
</tr>
<tr>
<td>300-330</td>
<td>0.016</td>
</tr>
<tr>
<td>330-360</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.080</td>
</tr>
</tbody>
</table>

The table shows that some 37 per cent of the ships have courses between 30 and 60 degrees and that some 47 per cent of the ships have speeds between 8 and 12 knots. The peak of the distribution is formed by ships having both courses between 30 and 60 degrees and speeds between 8 and 12 knots – more than 19 per cent of the ships have these properties. Thus ships travelling in the north east direction are the most frequent at the moment of the survey. About 16 per cent of the ships are crossing the main lanes approximately at right angles.

While speeds, courses and positions of the encountered ships can be determined with some approach to accuracy, their dimensions due to imperfection of the ship identification have to be derived from other data. For example, with the aid of the relationship shown in figure 5 ship's length distribution can be evaluated, if the speed distribution is known. Ship's size plays a rôle in the determination of the ship domain [4], i.e. the water area around a ship which
a navigator would like to keep free from other ships and stationary objects.

6. Final remarks and conclusions

By the method described here it is possible to obtain at comparatively low cost realistic traffic data, by which each measure for the improvement of safety in sea traffic can be substantiated objectively. It would be welcome, if other offices could resolve to conduct similar investigations on other shipping routes. In this way sea traffic the whole world over could be surveyed. To get more reliable data the survey should, of course, be carried out not only once, but repeatedly. Statistical traffic data such as obtained here will help the calculation of the collision rate.

Our present survey has shown, among others, that on shipping routes on the open ocean two-way traffic is predominant. This means that in most cases one is either sailing in the direction of a flow of traffic having to do only with oncoming vessels, overtaking vessels and vessels to be overtaken or one is crossing the road having to notice only both contrarily directed traffic flows. Crossing traffic, on the other hand, has occurred only rarely. Another result of this survey is that on most places ships are equally likely distributed over a wide range. This is also true of shipping lanes, if the sea room is large enough for the

Figure 5:
Speed vs. length of German merchant ships built after 1945 (excluding passenger ships and fishing vessels)
ships to spread out. The number of encounters per hour at own ship's average speed of 12 knots seldom exceeds 2 on shipping routes on the open sea, and the traffic density takes on values up to about 0.003 ships per square mile. On the other hand, in certain areas traffic density is sufficiently high to justify the introduction of a more powerful communication system such as vhf voice radio safety system to replace the present mf telegraphy and telephony systems.

There seem to be some dissimilarities between the model of sea traffic which some people treasure in their hearts with a nostalgic view back to those golden years when they used to go to sea and the intricate network of dates concerning composition, density, distribution in time and plane of speed and course and of behaviour patterns which was revealed by this research program, however small in terms of effort and cost it was. But even those men now in command of vessels often give a picture which differs from our results. One explanation might be sought in psychology: Masters of ships are undoubtedly in their great majority responsible, reasonable and anticipating men. It appears, however, that their reports sometimes reflect more what they expected and feared to happen or what they intended to do and tried to realize than what they actually experienced.

One example is the story of large ships going east in the deep water route at the north of the Sandettie Bank and having to take avoiding action by turning to starboard for small vessels coming straight over the banks at constant bearing, a very disagreeable situation indeed with no sea room available and huge tactical diameters, endless stopping distances and other impediments at hand. We tried to verify this lore of the sea by at least one certified example of such situations, but we failed completely. Neither recent traffic surveys nor interviews with shipmasters confirmed occurrences like that to happen regularly. This does, of course, not mean that it would not happen at all, but its probability is very, very low. If vessels are crossing the banks from starboard then most of them will not be in a constant bearing, and if they are, there will be deep water available at starboard, except in a rather short part of the route, so that even if a southerly evasive course could not be steered for a very long time a full turn of the ship with full rudder would cope with the situation.

Another example for the discrepancy between truth and tale becomes evident from the records of the ocean segments of the voyage. Interviews with Captain Bachor confirmed that he intended to take his ship as far as possible out of potential danger zones by
keeping to the starboard side of the route which in this case was naturally suggested by geomorphical conditions. Counterchecks with other masters serving on that particular route led to the same result. Therefore one would suppose to see a two-peaked distribution of the observed passing distances and an imaginary center-line of the route on an appropriate plot. But we have not been able to confirm this assumption. There is no wellfounded explanation for this available at the moment. It might be, however, that the position-fixing capacities of the ships are simply not sufficient to confirm whether the masters' intentions had been complied with or not. If that be so, then the risk of collision will be effectively reduced simply by increasing the position-fixing capacity of the ships.

Let us join hands and forces to discover the facts at sea as was tried with this program and let us continue to be very mistrustful of our presumptions.

7. References


Appendix 1

Data of the ship

"Own ship" is TT "LAGENA", a ULCC, on which the traffic recordings were made. Figure 6 shows the silhouette of the ship. She has the following particulars [5]:

- Length o.a. ............... 351.45 m
- Length b.p. ............... 336.00 m
- Moulded breadth ........... 55.40 m
- Depth to maindeck ....... 28.75 m
- Draught .................... 22.35 m
- Block coefficient ........ 0.83
- Deadweight ............... 315 000 t
- Tonnage ................... 155 000 g.r.t.
- Total capacity of cargo oil tanks .... 390 240 m³
- Speed ..................... 15.25 kn
- Number of propellers .... 1

Propelling machinery: Bremer Vulkan/Stal-Laval geared steam turbine, max. 36 000 HP at 85 rpm.

Navigational and radio equipment: 2 radars, 2 gyro compasses with repeaters, autopilot with course and rudder angle recorder, magnetic compass, echosounder with depth recorder, doppler sonar log, pitometer log, steering monitor, visual radio direction finder, decca navigator, remote reading draft gauges, remote reading anemometer, mf-, hf- and vhf-radio equipment including selective calling receiver and decoder.

Manoeuvring characteristics of the ship are shown in figures 7 and 8 [6].

![Location of radar antenna](image)

**Figure 6**: Silhouette of TT "LAGENA"
Figure 7: Stopping capability of TT "LAGENA"
Curve a) distance made good vs. time
Curve b) speed vs. time after stopping the engines
Curve c) distance made good vs. time
Curve d) speed vs. time with engines full astern

Figure 8: Turning capability of TT "LAGENA"
Track a) Vessel loaded, rudder hard to port, engines full ahead, initial speed 14.7 kn, final speed 4.6 kn, time for full turn 14 min 45 s
Track b) Ballast condition, rudder hard to port, engines full ahead, initial speed 15.0 kn, final speed 4.8 kn, time for full turn 17 min 54 s
Track c) Ballast condition, rudder hard starboard, engines full ahead, initial speed 15.6 kn, final speed 5.9 kn, time for full turn 12\textsuperscript{m} 43\textsuperscript{s}.

Track d) Vessel loaded, rudder hard starboard, engines full ahead, initial speed 13.5 kn, final speed 2.9 kn, time for full turn 14\textsuperscript{m} 22\textsuperscript{s}.

Appendix 2

Estimation of course and distance made good, given the positions of the ship

The calculations given in the following can be performed either by hand or by an electronic computer. The method given here is only valid for small differences of latitudes and longitudes respectively.

Let the latitude and longitude of point of departure A be, respectively, $\varphi_A$ and $\lambda_A$, and the latitude and longitude of point of arrival B $\varphi_B$ and $\lambda_B$. (North latitudes and east longitudes are positive, south latitudes and west longitudes negative.) Let further be

$$b = \varphi_B - \varphi_A$$

and

$$l = \lambda_B - \lambda_A$$

Then the mid latitude $\varphi_M = \varphi_A + 0.5 \, b$

and the departure $a = l \cos \varphi_M$

(a in nautical miles, $l$ in minutes)

$b$ not equal 0:

Let be

$$\varepsilon = \tan^{-1} \left( \frac{l}{b} \cos \varphi_M \right)$$

with

$$-\frac{\pi}{2} < \varepsilon < +\frac{\pi}{2}$$

Then, if $b$ positive and $l$ not negative, course made good

$$\gamma_0 = \varepsilon,$$

if $b$ positive and $l$ negative,

$$\gamma_0 = 2 \pi + \varepsilon,$$

if $b$ negative,

$$\gamma_0 = \pi + \varepsilon.$$

Distance made good

$$d = \frac{b}{\cos \gamma_0}$$

(d in nautical miles, $b$ in minutes)
b equal 0:
If l positive, then course made good
\[ \psi_o = \frac{\pi}{2} \]
If l negative, then
\[ \psi_o = \frac{3\pi}{2} \]
If l equal 0, then ship has not changed position.
Distance made good
\[ d = \frac{|1|}{\cos \psi_M} \]
(d in nautical miles, l in minutes)

Appendix 3

Estimation of target's true course and speed, given target's relative velocity and own ship's data of motion

The steps given in the following are ready for calculations either by hand or by an electronic computer.

Let be
- \( V_o \) own ship's speed (known),
- \( V_t \) target's speed (to be estimated),
- \( V_r \) relative speed (known),
- \( \psi_t \) own ship's true course (known),
- \( \psi_t \) target's true course (to be estimated),
- \( \beta \) relative speed direction (known). \( \beta \) is measured from own ship's heading in clockwise direction and has the value nil for targets appearing apparently on reciprocal course, see figure 9.

Then target's speed is
\[ V_a = (V_o^2 + V_r^2 - 2V_oV_r \cos \beta)^{\frac{1}{2}}. \]

From the figure
\[ x = V_o \cos \psi_o - V_r \cos (\psi_o + \beta) \]
\[ z = V_r \sin (\psi_o + \beta) - V_o \sin \psi_o. \]

If \( z \) positive, then target's true course
\[ \psi_a = \frac{3\pi}{2} + \tan^{-1} \frac{x}{z}. \]

If \( z \) negative, then
\[ \psi_a = \frac{\pi}{2} + \tan^{-1} \frac{x}{z}. \]

If \( z \) equal 0 and \( x \) positive, then \( \psi_a = 0. \)
If \( z \) equal 0 and \( x \) negative, then \( \psi_a = \pi. \)
If both \( z \) and \( x \) are 0, then target is not moving.

Figure 9: Geometry of velocity triangle
MARITIME TRAFFIC SYSTEMS USING SHORE-BASED RADAR

P.A. Carol*

Summary

The increasing traffic in confined waters, port areas and inland fairways demands more effective means of navigation. Shore-based radar systems can provide adequate navigational assistance. A number of operational and technical aspects of these systems are discussed. Some systems in which computers are used to store and process various information such as itineraries, are briefly described.

1. Introduction

The safety of ships navigating confined waters such as harbour approaches and inland fairways is causing more and more concern. This is understandable because:

- traffic density has increased considerably
- size and speed of modern ships have increased too, rendering them far less manoeuvrable in narrow waterways
- dangerous and polluting cargoes form a special threat
- also inland water traffic, with its unwieldy freight barges and ever growing numbers of pleasure craft, is playing a role of growing importance.

All these factors contribute to the growing necessity for more effective water traffic handling.

Government and Port Authorities are constantly on the look-out for means to increase the safety of shipping and maintain a continuous flow of shipping in poor visibility and other adverse climatic conditions, so that maximum efficiency and usage of harbour facilities is obtained. Reducing the idle-time of ships

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berthed in the port-area is probably the most attractive aspect from the ship owner's point of view.

The electronic industry is engaged in providing techniques that can be applied to solve these problems. Trials have been and are still held to investigate the feasibility of various favoured techniques, and the results should provide for much improved methods of navigation than those presently employed.

Navigational aids available at the moment are mainly directed to shipborne use, a matter of tradition and because of the problems of delegating legal responsibilities in cases of accident.

Areas of present development work

Considering all these factors, three main areas of interest for present development work can be indicated:

a. extending the effectiveness of current navigation systems
b. provision of integrated ship's navigation systems, particularly in the field of collision avoidance
c. provision of shore based systems for navigational assistance in confined waters, leading to more effective surveillance, traffic control, and use of harbour facilities.

In this paper some of the principle aspects of maritime traffic systems using shore based radars are discussed.
MARITIME TRAFFIC CONTROL
ALL VESSELS ON A STRING?
2. Shore based radar systems

Growing traffic density nowadays necessitates more than just the ship's precise position and course to be known on board. It requires information as to the ship's environment, the identity, position and course of other ships as well, and their proximity to each other and any danger situations arising.

This is especially true in confined waters. There a ship is no longer alone but one of a number of vessels entering or leaving the same area. In this situation one of the most suitable means for providing the specific and detailed traffic information necessary to guide a safe passage to and from the ship's berth are considered to be shore based radar systems of varying degrees of sophistication. Experience gained with such systems proves that the above statement is really true.

Shore based radar systems can be designed ranging from simple position determination and identification systems mainly consisting of primary radar and VHF communication, to more sophisticated systems with automated position determination, ship-shore and shore-ship communication providing for position reporting and normal VHF communication and a number of other facilities, so that the shore based observer can render the navigational assistance required and ultimately control the flow of water traffic.

3. Operational and technical aspects

To achieve the prime requirements of maritime traffic control, i.e. increasing the safety of ships entering, leaving and passing through the port area, and smoothing the flow of traffic between sea and berth, a number of operational aspects can be appraised.

a. The system should be designed in accordance with the traffic rules in the area concerned. These rules include both the laws already in force as well as extra rules for particular local application. Keeping in mind that the ultimate goal is
to achieve some form of traffic control within these rules it will be necessary to define as special rules the issuing of binding advice to an individual ship or group of ships as to procedures to follow in a certain situation or particular area.

b. The system should gather all necessary information concerning the itinerary of the ship such as harbour of departure and of destination, ports of call, estimated times of arrival and departure, cargo load, etc. These details being correlated into the ship's schedule, such schedules today being limited mainly to seagoing vessels.

c. The system should gather all necessary information concerning the meteorological and nautical situation at hand and to be expected over a certain period of time.

d. The system should provide means for continuous and unambiguous measurement of ships positions in the area concerned, these measurements being also correlated into the various schedules if available.

e. The system should provide for a block arrangement to simplify VHF radio traffic in relation to the coverage of the measurement system to be applied. An example of such a block arrangement is given in figure 2. In this figure the relation between VHF communication and the applied coverage of the radarchain is clearly indicated.

Figure 2: Elbe radar chain from Scharnhörn to Schulau. Two central control stations are located at Brunsbüttel and Cuxhaven, respectively. Every area has its own VHF communication channel.
f. The system should provide means for carrying out a well coor-
dinated pilotage which has to be considered as an integral
part of all safe entry and exit of port area's for seagoing
vessels.

g. The system should provide means for giving navigational
assistance to ships in the particular areas concerned.
This assistance is normally given by voice contact over VHF
radio between the shore based observer and the ship's navi-
gator, providing information as to its position and that of
other ships and or obstacles and special situations in its
immediate vicinity.
Two types of assistance can be distinguished. One is that
which offers ships individual advice, one at a time. The other
is group assistance, which provides certain categories of
ships, for example inland traffic with information of a more
general nature such as the traffic situation expected.
It should be noted that this advisory control must never
result in the 'remote control' pilotage of ships from ashore,
because a shore based observer cannot be expected to predict
the behaviour of a vessel under the prevailing circumstance.
Within the procedures established the Captain and Pilot must
retain the final say in the handling of the ship as their
exclusive responsibility.

h. The system should provide means for distribution, display and
registration of all relevant information in a format that is
most suited to the various users of the system.

i. The system should provide for a centralized display of the
total traffic situation in the area concerned in order to
enable control of the traffic flow up to a level the traffic
rules allow for.

j. The system should provide for a number of user support func-
tions enabling them to carry out their specific tasks effi-
ciently.
As examples of such support functions there can be mentioned:
. on request provision of all ship's itinerary information as
momentarily available
on request provision of meteorological and nautical information as momentarily available

- on request calculation of closest point of approach (CPA) for ship-ship and ship-reference position

- on request calculation of ship's position in terms of distance to reference point and deviation of reference line

- on request calculation of future traffic situation on the basis of ships' intentions and actual behaviour in which the time lapse can be varied as a parameter

- automatic alerts for collision danger (i.e. an extension of CPA calculations), buoy drift, extensive deviations from course to follow, possibility of grounding, etc.

The above list of operational requirements should be appraised as a general framework, which can be worked out fully or in part when starting implementation for a specific application.

Inferred operational aspects

The main operational aspects mentioned above indicate that information gathered in the system, especially the ship's itinerary, will be very useful in coordinating various harbour activities such as:

- coordinating aid in the use of tugs and linesmen and other auxiliary operations

- assistance in coordinating fire tenders, salvage services, casualty clearance and other emergency operations

- collecting and providing information of a commercial nature in relation to shipping movements.

Activities of this kind can be regarded as inferred operational aspects because they are not necessarily part of the actual maritime traffic system, but part of an existing organizational structure which will continue to exist besides the traffic handling activities.
3.1. Technical aspects

Considering the technical means of composing shore based radar systems which will serve the purpose, we can mention:

Radar systems

In most cases radars are employed operating in the X-band (8-12.5 GHz). However, for use in harbour basins and narrow waterways where only restricted ranges are required (3-5 km), Ku-band radars (12.5-18 GHz) can be used. The difference in wavelength (3.2 cm for the X-band and 1.8 cm for the Ku-band) implies that an aerial of the same dimensions will yield an azimuth resolution about twice as good. It can be easily understood that this is a big advantage because in shore based radar systems it is of prime importance that the radar echoes depicted on the display screens resemble the reality as closely as possible to allow a responsible navigation aid.

Radar parameters

Some of the main radar parameters will now be considered, assuming the following rough specification:
- detection of large and small ships in confined areas
- ranges of about 60-4000 m. In emergencies such as failure of a neighboring radar station the range required may be about 8000 m
- resolution and accuracy in the order of 7.5-10 m.

a. aerial rotation speed

Assuming a target speed of about 5 m/s and a resolution of about 7.5 m we find that a data renewal interval of 3 s is sufficient. The target has then moved 15 m, twice the position error. The renewed information is displayed as such and offers a positive contribution to e.g. track updating in an automatic system. The data interval of at least 3 s is equivalent to an aerial rotation rate of 20 RPM.
b. horizontal beamwidth

If an end-fed slotted waveguide aerial is used, the length of the slotted waveguide, which determines the horizontal beamwidth, is limited by the radar pulse length $T$ desired in relation to group delay effects. In this case $T = 50$ ns, dictated by the assumed range resolution of 7.5 m. Here, an aerial length of 5.5 m seems to be the maximum when a reasonable pulse form is to be kept.

Another limitation is set by the mechanical problems encountered in quickly rotating very large antennas which necessitate heavy and costly structures. A third reason to limit the aerial size is that in large aerials the Fresnel region is rather extended (about 2 km in the X-band for a 5.5 m aerial). Within this region the beam is not yet optimally formed and the physical aerial size is influencing the resolution. The effect of the beamwidth reduction then is affected by the longer aerial size. An aerial size of 5.5 m in the X-band results in a horizontal beamwidth of $0.4^\circ$ for a linear aerial system. The same aerial size would result in a horizontal beamwidth of $0.25^\circ$ in the Ku-band.

All values are given at the $-3$ dB points.

c. vertical beamwidth

In view of aerial performance, a beamwidth as narrow as possible is desirable (in the order of $4^\circ$ at $-3$ dB). To obtain a good coverage, the vertical radiation pattern is usually chosen to have an inverse cosecant square shape. In the Ku-band, however, radar performance is much more influenced by attenuation due to rain and fog. To keep an acceptable signal-to-rainclutter ratio for nearby objects in this frequency band an inverse cosecant shape is preferred to reduce the danger of objects with small reflective areas to be undetectable.

d. side lobe levels

The acceptable side lobe level is determined by the requirement that a side lobe echo of a large target shall not prevent the main lobe echo detection of a small target. If a signal-to-noise ratio of $18$ dB (for $P_d = 50\%$) is assumed, and a tar-
get cross section ratio of 33 dB (5 m$^2$ - 10.000 m$^2$), a side lobe level of at least -25.5 dB results. Of course, better values will reduce side lobe echos further.

e. polarisation

When choosing horizontal or vertical polarisation it should be realised that in literature a marginal advantage for vertical polarization sometimes is expressed.

---

**Figure 3**: Blockdiagram of duplicated radar system with associated monitor display, remote control and signalling equipment and data transmission equipment. (equipment at receiving end not shown)
At large ranges the low grazing angle, present in that case, will point to vertical polarization, especially if the sea is rough. At shorter range, with generally larger grazing angles, the choice is much more arbitrary. Because most navigational radars employ horizontal polarization, vertical polarization will be advantageous with respect to the possibility of interference.

Circular polarisation on X-band is not considered to be cost effective with respect to the rather large target areas and limited ranges. Besides, the detection of buoys equipped with corner reflectors is strongly affected by circular polarisation.

However, the improvement in signal-to-rainclutter ratio imposed by circular polarization, which is especially important in the Ku-band, brings about the possibility to introduce
circular polarisation in switchable form. This is regarded as an acceptable compromise.

f. pulse length
The range resolution of 7.5-10 m desired, leads to a pulse length of about 50 ns.
Besides, as rise and decay times cause the pulse form to be practically triangular, the radial resolution becomes smaller than the nominal pulse length. A smaller pulse length which might be desirable with respect to resolution, brings about other problems, e.g. pulse distortion caused by the aerial length when using slotted waveguide antennas, already mentioned under b.

g. p.r.f.
With an eye to the use of automatic video extraction, 5 to 10 hits per scan is considered to be a good value.
At a horizontal beamwidth of 0.10 and an areal rotation rate of 20 RPM this means that the p.r.f. should be in between 1500 Hz and 3000 Hz.
At a horizontal beamwidth of 0.250 keeping the areal rotation the same these values change to 2400 Hz and 4800 Hz.
Also with an eye to the use of automatic video extraction it is advisable to establish direct relationship in timing between the antenna azimuth value and the radar sync.
This can be achieved by synchronizing the transmitter sync. with the areal pulses indicating the changes in azimuth value.
If for the number of azimuth pulses 8192 is chosen a p.r.f. can be calculated of about 2731 Hz which is a quite acceptable value in both cases mentioned above.
With this p.r.f. the areal rotation between two consecutive transmitted pulses is about 0.7 mrad, equivalent to about 4.2 m on a distance of 6000 m. This value is compatible with the accuracy requirement of 7.5-10 m.
A p.r.f. of about this value is also favourable with respect to the fact that the first trace interval is about 54 km, rendering the possibility of second trace echos occurring negligible.
h. transmission power
The generally large targets and relatively small ranges do not impose heavy requirements on transmitting power.
The following table give range calculations for an X-band radar featuring 30 kW peak-power, a p.r.f. of 2731 Hz, a pulse length of 50 nsec a horizontal beamwidth of 0.4°, an antenna rotation speed of 20 RPM and a noise figure of 10 dB and a Ku-band radar featuring the same parameters except for the peak-power and the horizontal beamwidth, which are 60 kW and 0.25° respectively.
**Table 1: X-BAND RADAR SYSTEM**

### RADAR RANGE CALCULATION

\[
R^2 = \frac{P_{\text{ave}}.G^2.\lambda^2.\sigma.T}{(4\pi)^3.K.T_0.NF.S/N.Lt.St.Prt.}
\]

### RADAR PARAMETERS

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Value</th>
<th>POSITIVE VALUES</th>
<th>NEGATIVE VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (average) (W)</td>
<td>(P_{\text{ave}})</td>
<td>4.09</td>
<td>10 (\log P_{\text{ave}})</td>
<td>6.11</td>
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<tr>
<td>Antenna gain (dB)</td>
<td>(G)</td>
<td>35</td>
<td>2 (x G)</td>
<td>70</td>
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<tr>
<td>Wavelength (m)</td>
<td>(\lambda)</td>
<td>3.2(\times10^{-2})</td>
<td>20 (\log \lambda)</td>
<td>29.9</td>
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<tr>
<td>Radar cross section (m²)</td>
<td>(\sigma)</td>
<td>10</td>
<td>10 (\log \sigma)</td>
<td>10</td>
</tr>
<tr>
<td>Time on target (sec)</td>
<td>(T)</td>
<td>2.2(\times10^{-3})</td>
<td>10 (\log T)</td>
<td>26.5</td>
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<tr>
<td>Boltzmann's constant (J/K)</td>
<td>(k)</td>
<td>(8.10^{-18})</td>
<td>10 (\log (4\pi)^3)</td>
<td>8171</td>
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<tr>
<td>Receiver input temperature (°K)</td>
<td>(T_0)</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Noise figure (dB)</td>
<td>(NF)</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Signal-to-noise ratio (dB)</td>
<td>(S/N)</td>
<td>17.8</td>
<td>-</td>
<td>17.8</td>
</tr>
<tr>
<td>((P_d=80%) VS (P_f=10^{-6}))</td>
<td>(S/N)</td>
<td>17.8</td>
<td>-</td>
<td>17.8</td>
</tr>
<tr>
<td>(fluctuating target)</td>
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<td></td>
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<tr>
<td>R.F. losses (dB)</td>
<td>(Lt)</td>
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<td></td>
<td>3</td>
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<tr>
<td>System losses (dB)</td>
<td>(St)</td>
<td>7.1</td>
<td></td>
<td>7.1</td>
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<tr>
<td>Propagation losses (dB)</td>
<td>(Prt)</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>257.11</td>
<td>94.3</td>
</tr>
</tbody>
</table>

\[40 \log R = 162.81\]

\[R = 11.7 \text{ km}\]
Peak power: 30 kW
Pulse length: 50 nsec
PRF: 2731 Hz
Rot. speed: 20 r.p.m.
Hor. beamw: 0.4°
Noise figure: 10 dB

In 4 mm rain (0.07 dB/km): approx. 10.8 km
In 16 mm rain (0.4 dB/km): approx. 8 km

For a fluctuating target with a radar cross section of
10 m², R = 11.7 km
For a fluctuating target with a radar cross section of
100 m², R = 20.9 km
For a non-fluctuating target with a radar cross section of
10 m², R = 15.8 km.
Table 2: Ku-BAND RADAR SYSTEM

RADAR RANGE CALCULATION

\[ R^4 = \frac{P_{\text{ave}} \cdot 2 \cdot \lambda^2 \cdot \sigma \cdot T}{(\frac{4 \pi}{3})^2 \cdot K \cdot T_0 \cdot \text{NF} \cdot S/N \cdot \text{St} \cdot \text{Pr}t}. \]

<table>
<thead>
<tr>
<th>RADAR PARAMETERS</th>
<th>SYMBOL</th>
<th>VALUE</th>
<th>POSITIVE VALUES</th>
<th>NEGATIVE VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (average) (W)</td>
<td>( P_{\text{ave}} )</td>
<td>8.2</td>
<td>10 ( \log P_{\text{ave}} )</td>
<td>9.1</td>
</tr>
<tr>
<td>Antenna gain (dB)</td>
<td>( \lambda )</td>
<td>40</td>
<td>2 ( \times \lambda )</td>
<td>80</td>
</tr>
<tr>
<td>Wavelength (m)</td>
<td>( \lambda )</td>
<td>1.675 \times 10^{-2}</td>
<td>20 ( \log \lambda )</td>
<td>34.5</td>
</tr>
<tr>
<td>Radar cross section (m²)</td>
<td>( \sigma )</td>
<td>10</td>
<td>10 ( \log \sigma )</td>
<td>10</td>
</tr>
<tr>
<td>Time on target (sec)</td>
<td>( T )</td>
<td>1.5 \times 10^{-3}</td>
<td>10 ( \log T )</td>
<td>28.2</td>
</tr>
<tr>
<td>Boltzmann's constant ((J/°K))</td>
<td>( k )</td>
<td>8.1 \times 10^{-18}</td>
<td>10 ( \log (\frac{4 \pi}{3})^3 \cdot k \cdot T_0 )</td>
<td>171</td>
</tr>
<tr>
<td>Receiver input temperature ((°K))</td>
<td>( T_0 )</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Noise figure (dB)</td>
<td>( \text{NF} )</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Signal to noise ratio (dB)</td>
<td>( S/N )</td>
<td>17.8</td>
<td>17.8</td>
<td>17.8</td>
</tr>
<tr>
<td>( P_d = 80% ) ( \text{VS} ) ( P_{fa} = 10^{-6} ) (fluctuating target)</td>
<td>( \text{RF losses} )</td>
<td>6.2</td>
<td>6.2</td>
<td>6.2</td>
</tr>
<tr>
<td>( \text{RF losses} )</td>
<td>( \text{St} )</td>
<td>8.7</td>
<td>8.7</td>
<td>8.7</td>
</tr>
<tr>
<td>Propagation losses (dB)</td>
<td>( \text{Pr}t )</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\[ 40 \log R = 164.7 \]

\[ R = 13.1 \text{ km} \]
Peak power: 60 kW
Pulse length: 50 nsec
PRF: 2731 Hz
Rot. speed: 20 r.p.m.
Hor. beam: 0.25°
Noise figure: 10 dB

In 4 mm rain (0.24 dB/km): approx. 9.6 km
In 16 mm rain (1.2 dB/km): approx. 5.7 km

For a fluctuating target with a radar cross section of 10 m², \( R = 13.1 \text{ km} \)
For a fluctuating target with a radar cross section of 100 m², \( R = 23.3 \text{ km} \)
For a non-fluctuating target with a radar cross section of 10 m², \( R = 17.7 \text{ km} \).
j. accuracy

In so far as the radar contributes to accuracy, it can be noted that the latter can never exceed the lower limit determined by the radar parameters. These determine the range and azimuth increments which influence the accuracy directly. The increments are:

- in range 7.5-15 m
- in azimuth 0.7 millirad, equivalent to:
  0.7 m at 1000 m
  2.8 m at 4000 m and
  4.2 m at 6000 m.

k. resolution

The radial resolution will be 7.5 to 15 m, depending on target size. The azimuth resolution is given in Table 3 as a function of range for an aerial with a horizontal beamwidth of 0.4°. Separate values are given for small targets (buoys) and large ones (seagoing ships), because the effective beamwidth - i.e. the angle within which the radar receives detectable returns from a target - is also determined by the target size.

Figure 4: Radar picture of the entrance to the ports of Rotterdam and Europoort.
Table 3

Azimuth resolution for a radar having a horizontal beamwidth of 0.4°.

<table>
<thead>
<tr>
<th>Range</th>
<th>Resolution for small target ( (\Theta_{-3\ dB} = 0.4^\circ) )</th>
<th>Resolution for large target ( (\Theta_{-20\ dB} = 1^\circ) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000 m</td>
<td>28 m</td>
<td>70 m</td>
</tr>
<tr>
<td>3000 m</td>
<td>21 m</td>
<td>52 m</td>
</tr>
<tr>
<td>2000 m</td>
<td>14 m</td>
<td>35 m</td>
</tr>
</tbody>
</table>

The minimum azimuth resolution will be 5.5 m being the antenna length.

If a horizontal beamwidth of 0.25° is employed the resolution is improved by a factor of about 1.6. This results in an azimuth resolution at 4000 m of about 18.5 m and about 9 m at 2000 m. This does not fulfill the starting point specification (an overall resolution of about 7.5-10 m) completely, but it can be regarded as acceptable for the purpose envisaged.

Display systems

For the presentation of radar information in shore based radar systems the well known display techniques can be employed. Special requirements are primarily the short ranges, the possibility to depict reference lines and marks (e.g., the limits of navigable water), the possibility of easily changing and moving (off-centering) pictures, and the possibility of making azimuth and distance measurements from a number of predetermined positions, i.e. a salient point ashore such as a light-house.

Presentation of raw video in daylight, often desired by radar observers, cannot be realized by normal displays. Here a so-called digital scan-converter helps. This device converts the radar video into digital signals, stores them in a memory, and feeds them to a daylight display with the necessary high repetition frequency. The presentation is realised by writing a TV frame of 896 lines with 896 elements per line. In this way a very
bright picture is obtained which can be called a faithful copy of the original raw radar picture.
Taking into account the accuracy and resolution desired and also the improvement of equipment life time, the digital scan converter is a real step forward as compared to existing analogue scan converters which are based on the conversion of a radar picture into a TV picture by means of a storage tube. The original radar picture on this tube is scanned electronically according to a TV frame pattern. The TV signal obtained is then used for the presentation.

Computer systems
To aid radar observers some tasks can be automated by computers. On the analogy of air traffic control systems computers can be used for:
- assembling itinerary information
- gathering nautical and meteorological information
- gathering information for pilotage
- automatically, or semi-automatically following ships by primary and/or secondary video extraction techniques
- correlating the various information gathered
- bringing the correlated information on to the radar screens or Electronic Data Displays (EDDs) for the benefit of radar observers, traffic controllers, pilot despatchers and other authorities involved in ship handling
- calculating ships' movements in relation to environment (e.g. detecting excessive divergences from a predetermined and prescribed course) and in relation to each other (detecting dangers of collision and predicting congestion areas).

The development of shore based radar systems using data processing with computers is still in an early stage.

Means of identification
Just like air traffic control, maritime traffic control needs a system to identify ships in the approach and harbour areas continuously and unambiguously. In air traffic control this system
consists of secondary radar, i.e. every aircraft is equipped with a responder which automatically sends information as to identity and height as soon as it receives an interrogation pulse from a secondary radar. The position then is determined by the interrogating aerial's azimuth and the time lapse between the interrogation pulse transmission and the reception of the answer. In maritime traffic, secondary radar is recognized to be a means to realize the identification. Selective interrogation will allow calling one ship at a time, thus simplifying the data handling and reducing the possibility of errors. The same interrogation process is also suggested for use in VHF radio communication. In this case a responder is required on board as well, while at least two DF stations are needed to determine the position. As yet these systems are hampered by the lack of international standards and by the fact that extra equipment is needed on board, either as a permanent installation or carried on and off by the pilot. Lacking prescription, ship owners and pilots are not enthusiastic about such investments and the personal efforts entailed. Very soon, by the application of VHF-DF, stations in the approach areas can be expected to perform a first identification. The data thus produced will be fed into one or more displays which simultaneously show the radar information of the same area.

Data extraction systems

Although the secondary radar solution to the problem of identification is not expected to be applied in short time, the elegance of such systems and the already existing proof of the technical feasibility should be kept in mind for the future. In principle a secondary radar system for application in a maritime traffic system can be configured as shown in figure 5.
1. radar transmission pulse
2. interrogation code
3. responder transmission pulse

Figure 5: Principle set-up of secondary radar system using selective interrogation.

The basic process applied in this system can be described as follows:
- the expected positions for all ships equipped with a responder have been obtained by means of a computer with the aid of the results of preceding measurements
- one ship after another is interrogated in the order of their positions on the basis of the sense of rotation of the antenna. Interrogation is by means of the ship's responder address code which is sent by a code transmitter operating at a frequency $f_2$
every time a ship is interrogated the address code unblocks the responder on board the ship with the appropriate address code set.

The gate circuit is opened.

- the next radar pulse of the primary radar starts the responder. Therefore the responder is equipped also with a video receiver for the radar pulses.

- the responder answers by means of a short pulse eventually accompanied by the identification code (which can be the address) at the frequency $f_1$.

- when the responder signal is received, the responder receiver applies it to a data extractor, which unit uses the signal to determine the ship's position.

- the ship's position and the eventually accompanying identification code is transmitted to the computer.

- the computer uses the position and identification information to update the ship's position information as known in the system and to predict the new ship's position at the next scan of the antenna.

By application of this technique and choosing the frequencies $f_1$ and $f_2$ in the same frequency band as applied for the radar system it is possible to obtain a very high degree of accuracy in the order of $0.1^\circ$ in azimuth and 10 metres in range at the same time achieving a continuous and unambiguous identification of ships sailing the area concerned.

Today the use of primary video extraction systems is promoted as the short term solution to the problem of automation on maritime traffic systems using shore based radar.

One of the reasons behind this is of course that there is no need for extra equipment on board and that all ships sailing the area can be tracked in the system.

The principle drawback of primary video extraction is however that no continuous and unambiguous identification of ships during their passage through the area under surveillance is ensured.

In practice this means that there is no 100% guarantee that at all times a label allocated to a track, being an identifier for
the associated ship's itinerary data will stay with that track. This is caused by such effects as:
- one echo correlating with more then one track, within the correlation gate
- more then one echo correlating with one track within the correlation gate
- track fading e.g. because of passing of ships in between the radar sensor position and the object causing the masking of the object and consequently loosing of the track.

Besides the above mentioned problems there are a number of other problems related to the specific environment that influence heavily the design of an optimal video extractor for application in shore based radar systems.

As main influencing factors can be mentioned:
- the resolution of the radar equipment
- the combination of receiver technique and extraction process
- the application of special techniques to improve the signal to clutter ratio
- the effect of dealing with echosizes varying from point targets to targets targeyly exceeding the radar resolution cell.

Of course these problems are especially true in confined waters where heavy traffic consisting of ships of different types occurs.

It is believed that ultimately video extraction in shore based radar systems can be applied for:
- primarily providing an up to date picture of the total traffic situation, including correlating positional data gathered with ships itineraries
- secondarily providing possibilities for conflict search, prediction, data distribution, etc.

It is also believed that in systems using extraction of the primary radar video operator assistance will stay necessary to overcome the problems of label switching, loosing of tracks, tracks leaving the surveillance area of one radar sensor and entering the surveillance area of the next radar sensor and first identification.
Only the use of secondary radar will make full automation in this respect possible.
To get good overview of the advantages and disadvantages of the application of either the extraction of raw radar video or secondary radar data extraction, the main differences are listed in the tables 4 and 5.

Table 4
Advantages and disadvantages of primary video extraction.

<table>
<thead>
<tr>
<th>PRIMARY VIDEO EXTRACTION</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADVANTAGES</td>
<td>DISADVANTAGES</td>
</tr>
<tr>
<td>- no extra equipment needed on board, either permanent or carried on and off by pilot</td>
<td>- no unambiguous identification</td>
</tr>
<tr>
<td>- possibility to track all ships in the area under surveillance</td>
<td>- multiple target environment</td>
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<tr>
<td>- shore based equipment relatively simple compared with secondary radar shore based equipment</td>
<td>- due to target characteristics</td>
</tr>
<tr>
<td></td>
<td>- no point target -</td>
</tr>
<tr>
<td></td>
<td>- relatively large tracking windows necessary</td>
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<tr>
<td></td>
<td>- complicated tracking process</td>
</tr>
<tr>
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<td>- less system resolution compared with secondary radar</td>
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<tr>
<td></td>
<td>- performance largely dependant of:</td>
</tr>
<tr>
<td></td>
<td>- clutter</td>
</tr>
<tr>
<td></td>
<td>- reflections</td>
</tr>
<tr>
<td></td>
<td>- target splitting</td>
</tr>
<tr>
<td></td>
<td>- less accurate in azimuth and distance compared with secondary radar</td>
</tr>
<tr>
<td></td>
<td>- no fixed reference position(s) on board</td>
</tr>
</tbody>
</table>
Table 5

Advantages and disadvantages of secondary radar data extraction (with coded responders)

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>- unambiguous identification</td>
<td>- extra equipment needed on board either permanent or carried on and off by pilot</td>
</tr>
<tr>
<td>- single target environment</td>
<td>- tracking limited to ships equipped with responder</td>
</tr>
<tr>
<td>- due to target characteristics - point target -</td>
<td>- shore based equipment relatively complicated</td>
</tr>
<tr>
<td>- relatively small tracking windows necessary</td>
<td>- no international standardisation achieved</td>
</tr>
<tr>
<td>- simple tracking process</td>
<td></td>
</tr>
<tr>
<td>- high system resolution</td>
<td></td>
</tr>
<tr>
<td>- performance independent of:</td>
<td></td>
</tr>
<tr>
<td>- clutter</td>
<td></td>
</tr>
<tr>
<td>- reflections</td>
<td></td>
</tr>
<tr>
<td>- target splitting</td>
<td></td>
</tr>
<tr>
<td>- fixed reference position(s) on board</td>
<td></td>
</tr>
</tbody>
</table>

Other systems
Besides the above mentioned means of composing maritime traffic systems, a number of other systems can play a role in a system package such as:
- wide band radio relay systems to transport radar video from unmanned radar stations to an operations centre
- systems for video transmission over coaxial lines for the same purpose
- narrow band radio relay links for monitoring and controlling equipment at unmanned stations
- systems for transmitting monitoring and control signals over telephone lines
- MF and VHF communication systems
- VHF-DF systems
- telephone systems
- teletype
- closed-circuit TV systems
- speech registration systems
- date and time indication systems
- systems collecting meteorological data such as water levels, wind force and direction, tide movements, visibility etc.

These systems are not discussed in this article.

Figure 6 : Basic shore based radar system

4. Examples of shore-based radar systems

A typical shore-based radar system is comprised of one or more radar stations with display and control facilities and ship-to-shore and shore-to-ship communications. If more than one station is present the display and control facilities may be centrally located, the communication with the unmanned stations being realised with radio or coaxial links as mentioned in Section 3. Fig. 6 shows a model of such a typical radar system, roughly showing the lines of communication between operators, ships, and radar system. The possibility to distribute ships' and other data to interested third parties is also indicated.

This distribution will mainly take place via telephone and teletype.
Extending the basic model, systems can be created which comprise more and more automatic functions. A first step is to implement a computer system with terminal equipment for the purpose of automating the "itinerary-processing".

Fig. 7 shows how this is achieved.

The terminal equipment preferred is the electronic data display (EDD) or tabular display with local editing facilities.

Figure 7: Shore based radar systems with computer-aided itinerary processing

This model makes it possible to implement the following basic functions:

- gathering and assembling itinerary information per ship such as:
  . harbour of departure
  . harbour of destination
  . parts of call
  . estimated time of arrival at pilot station, lock, harbour basin, anchorage position, reporting point, etc.
  . estimated time of departure
  . route information in area under surveillance
  . docking position
  . anchorage position
  . type of cargo
  . tonnage
  . ships name and radio call sign
  . pilots name and number
  . ships draft
- gathering and assembling nautical and meteorological information
- gathering and assembling information concerning pilotage.

The functions mentioned above are realised by acceptance and processing in the computer of inputs from the keyboards of the electronic data displays, correlating the inserted data into the existing data base and formatting the data to be displayed:
- distribution and display of data
- recording of data.

Extending the basic model further by addition of various forms by "radar processing" it is possible to create the more sophisticated maritime traffic systems the elements of which have been discussed already.

Figure 8 shows a model of a shore based radar system with computer aided itinerary processing combined with video extraction.

Figure 8: Shore based radar system with computer aided itinerary processing and video extraction
Figure 9 shows a model in which the application of secondary radar is added to the application of itinerary processing and video extraction.

![Diagram of Shore based radar system with computer aided itinerary processing, video extraction and secondary radar data extraction](image)

All these models show that direct voice communication between operator and ship always remains.

Only in figure 9, another connection is added, namely a data link e.g. by using part of the existing VHF transmission channel(s) for shore-ship communication, which could be configured in such a way that automatic transmission to the ship of information as to position, course and speed to assume and any deviations that might occur from the optimal course, is possible.

Only a system in which a continuous unambiguous identification is built-in such a link is thought to be significant.
AN EXPERIMENTAL AUTOMATIC VESSEL TRAFFIC SYSTEM FOR THE PORT OF SAN FRANCISCO, CALIFORNIA

C. Grauling*

Summary

The experimental automatic vessel traffic system which has been installed in San Francisco is described. Emphasis is on the system architecture and software features. The San Francisco vessel traffic system has fully automatic detection and tracking of all ships under radar surveillance. It provides the VTS watchstander with a variety of hazardous situation detection and traffic analysis services. A brief history of the development cycle is given. The existing system is described in terms of the services that it provides the watchstander. The system implementation is described in terms of the major software design concepts. The experience gained in San Francisco indicates that future automatic vessel traffic systems have certain desirable properties. These properties are discussed in the conclusion of this paper.

Acknowledgement

The San Francisco experimental vessel traffic system was originally designed and built by the Applied Physics Laboratory of Johns Hopkins University during the period of 1971 through June 1974. Magnavox Research Laboratory has been under contract to the U.S. Coast Guard to do system engineering and maintenance on the VTS since June 1974. A more detailed description of the San Francisco as implemented by the Applied Physics Laboratory is given in a system functional description document written by the Applied Physics Laboratory.1

1. Introduction

The United States Coast Guard is using the port of San Francisco as the prototype for vessel traffic systems. The vessel traffic control center situated on Yerba Buena Island in San Francisco Bay currently houses two independent vessel traffic systems. One system is the operational system which serves the San Francisco maritime community on a 24-hour/day basis. This system has radar coverage of a large portion of San Francisco Bay and the approach from the Pacific Ocean. It relies on communication (via VHF radio)

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between the individual ship's pilots and the control center. It is not an automatic system in the sense that there is no automatic processing of the radar data. The other system is the experimental automatic vessel traffic system. This system has special purpose radar video processors and digital computers to perform automatic detection and tracking of all the ships in the harbor. Another digital computer is interfaced to the radar processing computers. This computer is used to perform traffic analysis and display functions. The man machine interface is implemented by a set of eight display processors which are used to analyze watchstander service requests, communicate with the traffic analysis and display processor and update graphical CRT displays. This paper is a description of the San Francisco automatic vessel traffic system. The description is in three parts. The first part is a brief description of the hardware. The second part is a description of the function which the system performs. This is done in terms of services which the system provides to aid the watch­stander in his job of monitoring the state of the harbor. The third part is a description of the structure of the various programs which are used to implement the services.

2. Description of the San Francisco VTS (Automatic System)

The automatic system uses the radar video from the high resolution radars and manually entered information to create a data base. This data base is used to provide a set of information display services which help the watchstanders perform harbor surveillance more effectively. The automatic system hardware configuration and signal flow are shown in figure 1.

An Automatic Detection and Tracking Subsystem (see figure 2) performs the Automatic detection and tracking of all the ships within the coverage area of radar. Analog radar video, radar triggers and digital bearing are processed in the Radar Video Processor (RVP). The RVP is a special purpose digital processor which performs the detection of radar return from the set of ships in the harbor. It uses adaptive thresholding and pulse-to-pulse correlation to help in the detection of ships in the presence of sea clutter. The RVP is controlled by a dedicated general purpose minicomputer at the radar dwell level. It interrupts the radar computer after it has processed the video received on each dwell (180 usec after each radar trigger). The radar interrupt processor performs all the input/output required to control the RVP, accepts the RVP’s output data and communicates with the traffic analysis and display computer. The RVP has two types of channels (track channel and acquisition channel) which run simultaneously. The acquisition channel reports the approximate positions of radar return which is in a region not covered by a track channel. Track channels are assigned to regions of radar coverage by the radar computer, when acquisition hits have occurred with sufficient scan-to-scan correlation to indicate that a radar contact is apparently present. The radar computer program filters the time sequence of observed positions to compute a velocity and
Figure 1: SF Automatic VTS Block Diagram

Figure 2: Automatic Tracking and Detection Subsystem Block Diagram
position estimate for all radar contacts. These estimates are used to determine the required location of track channels on the next scan and are also reported to the Traffic Analysis and Display Subsystem for further processing.

The Traffic Analysis and Display Subsystem (TAD) consists of the TAD Computer Subsystem (see figure 3), a satellite display group (see figure 4) and a set of working displays (see figure 5) connected as shown in figure 1. The TAD computer subsystem is a Honeywell DDP-516 with 16K 16-bit words of memory and standard peripherals as shown in figure 3. There are two operator stations and one supervisor station. All three stations have a working display and a pair of vessel status displays. The working display is an interactive graphics terminal which contains a dedicated display computer (IMLAC PDS-1 with 8K of 16-bit core), a direct write CRT display, a keyboard and function key pad, and a trackball cursor positioning device. The vessel status displays are alphanumeric CRT displays. There are two such displays and each station has a monitor for each display.

The operator stations are equipped with the additional capability of satellite displays which are graphic displays which typically are used to display maps of the San Francisco harbor and the vessel traffic. There are five satellite displays and eight monitors (four monitors per operator) connected as shown in figure 4. The satellite display processors are IMLAC PDS-1 processors with 4K 16-bit words of memory.

Figure 3: Traffic Analysis and Display Computer Subsystem
Figure 4: Satellite Displays

NOTE: THE SATELLITE DISPLAY PROCESSORS ARE IMLAC POS-1's. THE SATELLITE DISPLAYS ARE DIRECT WRITE CRT DISPLAYS.

Figure 5: Working Display Block Diagram
3. Automatic VTS Functions

The operation of the San Francisco Automatic VTS can be described in terms of the services which it provides for the VTS watch­stander. All services are initiated and controlled via one of the three working display keyboards and associated function key pads. The services can be classified into three major categories. These three categories are: information storage and retrieval, traffic analysis, and automatic alert condition detection and analysis. The capabilities provided in each of these categories are described in this section.

Information Storage and Retrieval Services

Services in this category are used to enter information about vessels in the harbor and to control the format of the information which is displayed to the watchstanders. These services are: select displays, enter/exit, status display/edit, real-time data dump and running computer log. They are described in further detail in the following paragraphs.

The select displays service allows any operator to specify which of eight possible map displays is to appear at his own working display and on each of the five satellite displays. The entire San Francisco harbor area is covered by seven maps. Each map contains an outline of a section of the harbor. This outline is a set of graphics vectors which are refreshed by the display processor. In addition, the traffic analysis and display computer transmits contact update reports to the appropriate display processors for each radar contact in the system. Thus, a typical display consists of a map outline and a set of symbols which represent the location of all the tracked vessels on that map. The symbols move on the map display in accordance with position information obtained from the ADT.

The enter/exit service allows the watchstander to create and delete data files for the ships in the harbor. The system allows for thirty identified vessels to be active at any one time. The watchstander can request to enter a ship into the system at any time. If one of the thirty files is available, the system displays a blank vessel data page upon which the operator can type relevant vessel information. This information includes vessel name, route, pilot identifier, disposition, etc. When the watchstander is finished typing, the information is stored in a disk file by depressing a function button. When a vessel departs the system, the exit service is used to free the vessel data page for use by another vessel.
The vessel data pages may be displayed and edited via two status edit services. A subset of the vessel data page for any vessel in the system may be displayed and edited via the "mini-status" service. The name, disposition, and position of any vessel in this system can be displayed and edited in a corner of any map display without affecting the map display. The full vessel data page for the vessel may also be displayed and edited via a function button when the mini status service is active. This service allows the watchstander to edit any item on the vessel data page. In addition to the set of vessel data pages, there is another page of text which can be displayed and edited at any working display. This is used by the operators to keep navigation advisory information such as hazardous weather conditions.

The edit services allow the operators to create data files on vessels in the harbor system. The identify service allows the operator to correlate a radar contact with an existing data file. When the identify service is requested, the display processor prompts the watchstander to indicate the position of the radar contact on his synthetic display with a cursor and type in the vessel identification number. This indicates to the TAD computer that a given radar contact is the given vessel. Radar identified vessels become subject to a variety of automatic alert detection procedures which will be described in a later section.

In addition to the various display formats available at the working display graphics terminal, the automatic VTS displays information on the line printer automatically as a function of time and as a service available to any working display. The watchstander can request that the information from ADT associated with any three contacts be dumped on the line printer in real-time. This information could be used as a record of close encounter or collision situations. In addition, the system dumps the contents of the vessel data pages every fifteen minutes and prints any edits to the vessel data pages when they occur. This printout serves as a record of the harbor operation and a backup to allow the watchstanders to move over to the manual VTS in the event of an automatic system failure.

Traffic Analysis Services

There are two traffic analysis services (relative position and closest point of approach) available to the operator via the working display. The relative position service allows the watchstander to identify any pair of ships or geographic points and have the computer display their relative position. This service has been used to help ships without radar to navigate in poor visibility conditions. When the relative position service is active, the relative position information is updated every three seconds and the updated information is continuously available. The relative position information is displayed both graphically (via a relative position vector) and algebraically (via an alphanumeric display in the upper left corner of the working
The closest point of approach service is similar to the relative position service in operation. The major difference is the additional calculation of time and distance of closest point of approach based on both the current relative position and the relative velocity of the pair of contacts. The graphic display shows both contacts with their current velocity vectors projected forward to the point of closest point of approach and a broken vector demonstrating the relative position at the point of closest approach. This information is also displayed in alphanumeric form in the upper left corner of the working display map.

**Alert Detection Services**

This category contains those services which run continuously in the traffic analysis and display computer whenever it is not involved in the processing of radar contact update or other display service requests from the various working displays. These services are characterized by having the computer search the vessel database for specific potentially hazardous conditions and generating an alert message to all watchstanders upon detection of one of these potentially hazardous conditions. Typically there is an analysis service (alert response) associated with each of the alerts to aid the operator in tracking an alert. The set of alert conditions includes: collision warning, vessel movement report overdue, lane stray and grounding detection, critical point congestion and anchored vessel drift detection.

Collision warning alerts are generated whenever the closest point of approach and time to closest point of approach are below a distance and time threshold for any pair of identified vessels or for any identified vessel and unidentified large (>150 feet long) radar contacts. The alert response to this alert is a CPA display for the involved pair of vessels.

The vessel movement report overdue alert is associated with a reporting system which has been implemented on the Sacramento River. There is a set of checkpoints along the river. Each vessel is required to notify the VTS upon arrival at each of the checkpoints. The anticipated arrival time at the next checkpoint is entered at each checkpoint. The computer detects if a vessel is overdue with respect to the last entered anticipated checkpoint arrival time. When this event occurs, the computer causes the overdue vessel's disposition symbol on the Vessel Status Display to blink. There is no alert response associated with this alert condition.

If a given vessel is known to be on one of a set of predefined routes, it is subject to lane stray and grounding analysis. A lane stray alert is generated when a vessel's current position and velocity predict that the vessel will violate its predetermined lane boundary. In addition to maintaining a data file which contains the location of all the lanes, the computer has access to the harbor depth contour map. If a vessel's draft
is also entered on its vessel data page, the computer can predict if a straying vessel is in danger of grounding. The response to either a lane stray or grounding alert is a graphic representation of the offending vessel with a vector emanating from the vessel symbol to the anticipated point of lane stray or grounding.

Critical point congestion is another alert condition which is detected using the information associated with the lane discipline. There are two critical zones in San Francisco which have the property that at most one ship should be in either zone at any given time. Critical zones are typically the intersections of a set of lanes. The critical point congestion detection procedure dead reckons all ships along their respective routes for 20 minutes and checks for the condition that two or more ships will be in a critical zone simultaneously in the next 20 minutes. An alert is generated in the event of the detection of a congestion situation. The alert response is a graphic depiction of the condition and an alphanumeric display of the vessels involved, the zone, and the expected time of the congestion situation.

Another alert condition which is available to the operator is anchored vessel drift detection. The operator may specify that any radar identified vessel is anchored by editing the disposition entry using either the mini-status or full status edit service. The current position of the vessel is recorded at the instant of the edit. On all subsequent position updates associated with the anchored vessel, a test is made to determine if the vessel has moved outside a circle whose radius is determined by the size of the vessel and whose center is the vessel position at the time the vessel was declared to be anchored. The map symbol and disposition symbol associated with the vessel will blink in the event that the vessel has moved outside the test circle. This serves as an indication that the anchored vessel may have started to drift.

4. Software Description

There are three different programs present in the San Francisco Automatic VTS, corresponding to the radar computer, traffic analysis computer, and display processor. A brief description of the major features of these programs is given in this section.

Radar Computer Program

The processing of the radar computer can conveniently be broken into three levels: first priority processing (those tasks that must be accomplished on a dwell-by-dwell basis) second priority processing (those tasks that must be performed after a period
of several radar dwells), and third priority processing (those tasks that must be accomplished within three seconds or one radar sweep). There are no functions within the radar computer that may take more than three seconds to accomplish.

The interrupt executive controls the execution of the first and second priority processing. These are the tasks that must be accomplished within a specified number of radar dwells. The interrupt executive is entered once for every radar dwell. When the first and second priority tasks are completed, the interrupt executive returns control to the principal executive which controls the execution of all lower level (third priority) tasks.

First priority tasks consist of the following: keeping the I/O channels and their usage in order, inputting the radar bearing, outputting track channel assignments (gates), outputting data to the Traffic Computer, testing for good bearing data, and directing the track channel report processing and acquisition channel report processing based on their current status. All of these tasks are done each radar dwell and interrupts are not re-enabled until they are completed.

Second priority tasks consist of the following: Track channel report processing and acquisition channel report processing. The interrupt executive controls the calls to these routines, and since they may require several radar dwells to complete, the interrupt executive re-enables interrupts prior to the calling of these routines. This permits the first priority processing to interrupt the hit processing to complete the higher priority tasks. The interrupt executive keeps track of the processing that has to be completed. Each of the report processing routines utilizes two hit files, one that is being processed while the interrupt executive is directing input to the other. When the hit processing is completed, the interrupt executive returns control to the principal executive.

Third priority tasks consist of the following: monitoring the radar computer program constants, preparing the statistics record for outputs to the traffic analysis and display, clearing merge and update flags in the track file, updating the track file, and finally, ordering the tracks by bearing in the bearing index file. The principal executive controls these tasks with the only requirement that they be completed prior to the next radar sweep (in three seconds).

Traffic Analysis and Display Computer Program

The traffic analysis and display computer is the center of the star configuration network of digital processor which comprises the automatic VTS. The basic executive of the TAD computer program is the small multitasking operating system which was
furnished by the computer vendor (Honeywell's OP-16, Real-Time Executive). This executive provides a set of system functions which allows users to do priority multitasking with a minimum of system overhead. OP-16 allows user to define tasks as programs whose characteristics are defined in a set of executive tables. For example, executive tables consist of a program list (defining the set of programs in the system and their states of execution), an interrupt table (defining the location of interrupt processors associated with each device), a clock user's table (defining the set of programs which the system must schedule periodically) etc. OP-16 provides a set of system functions which allows programs to control their own execution and the execution of other programs in the system. This set of function calls includes the following functions:

1. Request Program - This function allows any program to schedule the execution of any other program. This will cause the requested program to be run at a later time depending on the requested program's priority and system load. Program requests are automatically queued by the operating system execution of queued requests occur on a first-out basis.

2. Schedule Label - This function allows any program to resume execution of another program which is waiting for the scheduling program to complete execution. This feature is typically used by interrupt processors associated with I/O devices to allow the calling program to resume execution following the completion of an I/O transaction.

3. Wait - This function allows an executing program to unschedule itself while waiting for some other event to occur. Normally the other event will schedule a label in the waiting program to allow execution to resume.

4. Connect/Disconnect Clock - The operating system can be directed to schedule programs periodically via a connect clock function call. This action can be terminated via a disconnect clock function call.

The TAD computer program has three major tasks which are requestable programs. The highest priority program is the Radar Management program. The radar management program is activated by the arrival of a radar contact update message from either of the radar computers. The processing of these messages includes coordinate conversion from a polar coordinate representation (with the origin at each radar) to a rectangular coordinate system (with origin at Yerba Buena Island), updating of the vessel's position and velocity table entries, test for anchored vessel drift (if applicable), radar coverage overlap processing and calculation of contact update reports for transmission to all applicable display processors.
The second highest priority program is the operator overlay executive. This program is responsible for handling operator service requests. Operator service requests are generated by working display processors in response to operators depressing any one of a number of function buttons. Each operator service request is accompanied by a data buffer which contains information indicating which operator service is requested and any parameters required by the requested service. The operator overlay executive examines this buffer and determines which overlay to bring in for execution. Each service is a program which is stored on the disk file and brought into core for execution as required. Since operator service requests are generated asynchronously and independently, the operator overlay executive must enqueue the requests and schedule the overlays on a first-in-first-out basis. The typical sequence of events which occurs when an operator requests a service is as follows. The operator requests a service by depressing a function button. The working display processor forms a service request message (depending on the function requested) and transfers it to the TAD computer. The operator overlay executive examines the message and schedules the required set-up overlay. The set-up overlay transmits a data file (called control matrix) to the working display processor which contains the information required by the working display processor to implement its role in the service. (This information is typically display format information such as operator data request prompts, etc.) Normally there are parameters which must be obtained from the operator for any given service (e.g., a status edit requires a vessel identifier). When the working display processor determines that the operator has input the required parameters, it transmits a message to the TAD computer containing the parameters. The operator overlay executive then schedules the proper analysis overlay which performs the required service and transmits the resulting display to the working display. Many of the services require updating of the analysis on a periodic basis. For example, any analysis which uses radar position information needs to be updated every 3 seconds. This is done automatically by the operator overlay executive. There are over 20 overlays which are handled by the operator overlay executive routine. These overlays are the processing for all operator services and alert response.

The third priority processing in the TAD computer is the background overlay executive. This executive cycles through a list of background tasks executing them as fast as possible. There is a background overlay associated with each of the alert conditions which were described earlier, (except for anchored vessel drift which is handled by radar management) and a core partition which is used solely by the background overlay executive for the execution of background tasks. Each background task is brought into core from disk when its turn to run comes up. In general, each task looks for some type of alert condition and if it is detected, the task enqueues an alert message to a core resident alert queue manager. (The alert queue manager is another scheduleable program with OP-16 program set.) The alert queue manager maintains a queue of alert messages in order of urgency. It
transmits display messages to all working displays indicating the alert on the top of its queue. When the alert response function button on any working display is depressed, the operator overlay executive is used to implement the alert response operator service and the alert queue manager is called to dequeue the top alert and display the next alert in the queue.

Display Computer Programs

There are two versions of the display computer program (corresponding to the satellite and working display programs). The satellite display can be displayed on a working display. Therefore, this description will be of the working display program with the understanding that features associated with the manual input of information are not present in the satellite display program. The working Display Computer processing is described under the headings of Interrupt Processing, Subroutine Processing, the Display Processor Program, and Satellite Processing in the paragraphs that follow.

Interrupt Processing. Most of the display computer processing is initiated by interrupt control. The display computer is programmed to respond to only two interrupts; an external interrupt from the Traffic Analysis and Display Computer, and an internal interrupt from the 40-Hertz display clock.

The external interrupt is initiated by the TAD Computer to send a 16-bit control, word which tells the display computer that it either wants to send data or wants to be sent data. The display computer can receive eight types of data transfers and can send back four different buffers of information.

The internal clock interrupt is used to turn on, or start, the display processing cycle; to schedule the time counter; to set the rate at which contacts will blink (presently on a 1/2 second cycle); to schedule the Error Message Processor every 1/4 second; and to read the Trackball X-Y coordinates.

Subroutine Processing. During the time when the display computer is not servicing interrupts, it is executing the programs scheduled in the following run list:

1. Keyboard Input
2. Keyboard Control
3. Data Read and Format
4. Data Output
5. Hook Processor

6. Operator Services

7. Keyboard Edit

8. Error Message Processor

If a subroutine, other than the keyboard input subroutine, is scheduled, it will be called from this list in the order of priority specified. Since the keyboard character control numbers, function buttons and leader augment buttons do not cause an interrupt, the Keyboard processor subroutine is always scheduled and has the highest priority of the subroutines.

A unique feature of the Working Displays is the fact that each selected service does not require a multitude of overlay subroutines to be transmitted, thus detracting from processing time. Instead, a control matrix of 156 words is transmitted for each service and remains core resident until another service is requested, regardless of the functions performed by the operator in that service. The control matrix allows only the subroutines necessary for that service to be performed; sets up the variables needed by the keyboard processors to display the input characters at their proper place on the display, and sets the proper labels for the function buttons, operator instructions, and page names.

The data format subroutine receives all data transfers from the Traffic Computer and stores the data into the appropriate files.

The page buffer output subroutine sends all the requested data to the Traffic Computer upon its command.

The Hook Contact Program (if the HOOK control button has been pressed) searches the contact display files (except the lost contact file), finds a contact within a small, fixed distance from a given X-Y position of the cursor, puts an octagon symbol around the contact symbol, and stores the track number in a special buffer. This tells the operator that the computer will refer to this contact in future services. If the SET control button had been pressed, the X-Y coordinates of the current cursor position are stored in the buffer and the position is marked with an "X". This tells the operator that the computer will refer to this position in future services.

The Keyboard Input Program inputs all keyboard and function button character codes and schedules the Keyboard Control Program. The Keyboard Control Program processes all keyboard and function button codes, selecting the proper response depending on the particular Control Matrix being used.
The Operation Control Program has four sequences of operations which it may perform. The operations for each sequence are specified by the control matrix. Each sequence is called after a key event has occurred:

Sequence 1 after a new service (control matrix) has been received;

Sequence 2 after the HOOK, SET, or CLEAR control buttons are pressed;

Sequence 3 after a message for the operator response area has been received; and

Sequence 4 after a block of data has been sent to the Traffic Computer. This provides for a flexible series of events for each service merely by changing words on the control matrix.

The Keyboard Edit Program puts all alphanumeric characters onto the text display, and stores them in a buffer for transmittal upon a request from the Traffic Computer.

The Display Processor Program. The Display Processor is the special purpose display hardware which is used to refresh the direct write graphics CRT. It has its own program which is a set of special graphics instructions and is resident in the Display Computer Core memory. The execution of the Display Processor Program is initiated by the Display Computer in the 40-Hertz interrupt processor. The Display Processor Program executes the given list of file subprograms for that service as set by the control matrix. The first part of this list contains all the text information to be displayed and is done with standard deflection voltages. When the processor has finished this part, it sends a special output command to the zoom hardware which turns the magnification circuitry on (if the button has been pressed to enable it). The last part of the list, containing the map-oriented information (outlines, contact symbols, cursor, etc.) is then executed. When the Display Processor halts, the zoom circuitry is disabled. This provides the mechanism to magnify the map but not the text information.

5. Conclusion

The implementation of the automatic vessel traffic system in San Francisco has proven to be a valuable experience. Some of the major conclusions which have been reached are:

1. Automatic detection and tracking of ships by shore based high resolution radar is useful and feasible.

2. Alert services which make use of position and velocity information require very high accuracy in order to avoid excessively high false alarm rates.
3. The high accuracy requirements imply that the ADT performance must be improved before the automatic system can realize full operational effectiveness. The radars used in the San Francisco Francisco system are the state-of-the-art in terms of resolution. However, sea clutter problems caused unacceptable errors in estimation of ship's velocities.

The U.S. Coast Guard is currently continuing research and development activities directed at defining the type of equipment to install in future Vessel Traffic Systems. A subset of the San Francisco Automatic VTS will be installed at the U.S. Coast Guard research and development facility in Groton, Connecticut. It will be used for further research in the area of automatic detection and tracking of ships using radar. In addition, the U.S. Coast Guard has a study contract with the Magnavox Research Laboratory to do the initial design work on a class of modular computerized vessel traffic systems. This effort involves the functional specification of an expandable multiprocessor configuration and of the algorithms which will be used in future VTS installations.

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AN INVESTIGATION INTO THE EFFECTIVENESS OF A PORT SURVEILLANCE RADAR THROUGH COMPUTER SIMULATION ANALYSIS OF RESULTS OBTAINED PRINCIPLES OF THE AID PROVIDED TO PORT OFFICERS TO TAKE A DECISION

T. Degré*
X. Lefevre*

The various systems dealing with navigation surveillance available to port authorities generally provide for traffic flow in good conditions, but how far can it be said that one such system is more effective than another? Is it possible to establish a scale of values for these systems, which will give a merit figure for each, according to the services rendered?

Summary of the First Part

This investigation consisted in setting up a simulation model making it possible to compare, for a given port and traffic flow, the consequences of the presence or absence of a port surveillance radar.

The comparison will be made based on
- waiting times of ships about to make a manoeuvre,
- safety of navigation in the approaches of and inside a port.

There are many reasons for a ship to wait, they result
- either from the lack of means for manoeuvring the ship (pilots, tugs, berthing places),
- or from unfavourable nautical (tide) or traffic conditions.

In this investigation we have only considered waiting times resulting from nautical and traffic conditions.

The model consisted in two separate sections:

1. - Simulation of port operation
2. - Characteristics of the presence or absence of a surveillance radar.

*Service des Phares et Balises - FRANCE
1. - Simulation of port operation

- The port is represented as a group of zones (Channel, outer harbour, docks, locks).

- The ships are characterised by their directions, types, the docks from which or to which they sail.

- They are assumed to arrive according to a Poisson type distribution with a parameter $\lambda$ (this assumption proved to be good in Le Havre harbour).

- The port authority is responsible for organizing and controlling the traffic in the harbour zone.

Ships always ask the permission of the port authority to begin their manoeuvres.

At their request, they are instructed by the port authority

- either to wait, because ships with a higher priority are already waiting. This decision is taken according to a number of previously fixed priority rules,

- or to begin their manoeuvres at a certain time.

This starting time, as near as possible to the time of application for permission, is determined by the port authority according to:

- movements already taking place in the port at the time of application,

- certain safety rules laid down by the port. In general these rules prohibit the simultaneous presence of certain types of ships in movement in the same port area.

At any time, when it is considered necessary and possible, the port authority may give instructions to a moving ship to stop or slow down, in order to avoid a dangerous situation.

2. - Characterisation of the presence or absence of a surveillance radar

The port authority organises and controls the traffic generally on the basis of estimations of the duration of the manoeuvre $d_z$ of different ships in movement in port areas.

The term estimation function of the duration of the manoeuvre $d_z$ of a ship in movement in a port area $Z$, at any instant $t$, will therefore be used for the function:
\( \beta_z(t, d_z) = d_z + E_z(t, d_z) \quad 0 \leq t \leq d_z \)

where \( E_z(t, d_z) \) is a function representing the error made on \( d_z \) at time \( t \) by the port authority.

A surveillance radar is an implement which makes it possible to know with precision, at any instant \( t \):
- the position of ships in movement,
- how they move during their manoeuvres.

The port authority can thus at any instant \( t \), re-estimate \( d_z \) and then correct the error made on \( d_z \).

Estimation functions characterising the use of radar are therefore continuous functions of \( t \).

When the port authority cannot use a radar, it cannot generally correct its estimations continuously and estimation functions are consequently discontinuous functions of \( t \).

The shapes of estimation functions can be obtained statistically for each port area with and without radar, if an important number of ships is considered; but pending the results of such an enquiry, it is felt that the absolute value of the functions \( E_z(t, d_z) \) decreases with \( t \), which intuitively indicates that the port officer is in a better position to estimate the duration of the manoeuvre of a ship when he watches her movement.

Finally the presence of a radar is characterised by a set of estimation functions, the error function of which is continuous and decreases with \( t \) in absolute value.

The absence of a radar is characterised by a set of estimation functions, the error function of which is a step function of \( t \), and decreases with \( t \) in absolute value, such that with any value of \( t \):

\[
\left| E_z(t, d_z) \right| \leq \left| E_z(t, d_z) \right|
\]

(with radar) (without radar).
Summary of the Second Part: Results of the Simulation

Once the model is adjusted, an economical study of radar effectiveness requires only making two simulations during a given time, one with estimation functions characterising the presence of radar, the other with those characterising the absence of radar; and then comparing the results obtained taking into account the above mentioned criteria. Since some data are still to be collected in ports, we are unable at the present time to arrive at conclusions as regards the economical study. However, the model has been tested using specific parameters for these data in order to appreciate the sensitivity of the results and the logic of the model.

Parameters have been affected, in particular, to the following data:
- estimation functions,
- initial errors, \( E(0, d_z) \), made by the port authority,
- arrival sequence of ships.

**Estimation functions**

Two types of these functions have been considered:

- **Favourable functions** (F): functions in which the error made by the port authority on duration \( d_z \) varies from the initial error to 0 in a very short time,

- **Unfavourable functions** (D): functions in which the error made by the port authority remains unchanged during almost the total duration of the movement of a ship.

These functions are therefore extreme estimation functions.

**Initial errors** \( E(0, d_z) \):

The durations of ships' manoeuvres are obtained in the model according to empiric laws. These aleatory variables are characterised by their mean value and \( E(0, d_z) \) is obtained by deducting the actual duration obtained in the model from the mean value.

Parameters have been selected for initial errors by multiplying \( E(0, d_z) \) by 1, 3 and 5, corresponding respectively to low, mean and very high initial errors.
Arrival sequence of ships:

5 sequences have been considered: on an average 60, 80, 100, 110 and 120 requests for entering or leaving a port each day.

Table I and the relevant curve show the influence of the arrival sequence, \( \lambda \), on the difference between the mean ships waiting times \( \bar{A}_D \) with unfavourable estimation functions and mean ships waiting times \( \bar{A}_F \) with favourable estimation functions.

In other words, \( \bar{A}_D - \bar{A}_F \) is the average improvement obtained with functions \( F \) as regards mean waiting times.
\[ x, y = x \text{ hours}, y \text{ minutes} \]

### TABLE I

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<thead>
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<th>( E_0 )</th>
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</table>

**TABLE I**

SHIPS MEAN WAITING TIMES, A, C
Summary of the Third Part: Principles of the aid to port officers to take a decision

The purpose of the third part of this investigation is to deduce through the simulation model, the main principles of a conversational system to be used by the authorities responsible for traffic organisation in port and its approaches.

These authorities are in charge of an operational system, which we shall call "PNR (1) System", placing at the disposal of its users - the ships - a number of resources: pilots and tugs, making it possible for them to manoeuvre in the port.

They organise and control the activity of the system according to:
- the operational port regulations,
- the limitations relating to the use of resources,
- users' requests,
the aim being to provide the users with services of the highest standard.

The effective organisation of the PNR System requires
- on the one hand, a continuous knowledge of the precise situation of the different components: which implies extensive, fast and reliable exchanges of information between the different responsible authorities;
- on the other hand, a right determination of the repartition of resources and a safe schedule of manoeuvres to be selected among a number of possible solutions, on the basis of short term forecasts.

Most of the time, the experience of operators and the use of common transmission equipment, makes it possible to achieve some efficiency in those two lines of action.

However the use of an adequate conversational system would make it possible in all conditions, for the responsible authority, to obtain a more reliable and quicker updating of the present situation of the PNR System.

Furthermore a conversational system would notably facilitate the constitution of many statistical card indexes required to have a precise knowledge of the activities of each component of the PNR System.

(1): PNR (Ports - Navires - Ressources) = Ports - Ships - Resources
Finally, in complex configurations, the conversational system would help responsible authorities to take a decision by providing them with some elements required to select the best solutions as regards the repartition of resources and the sequence of manoeuvres.

The conversational system which we propose is based on the three main principles:

1. Providing responsible authorities with a means to have a continuous knowledge of the situation of the different states of the PNR System. Ships and resources assume several possible states during their existence in PNR System. For example: waiting ship, moving ship, available resource, assigned resource, resource on the way.

   At the request of users the conversational system would constitute and update a certain number of card indexes corresponding to the various possible states of ships and resources.

   Looking at these card indexes makes it possible for responsible authorities to obtain rapidly the required information on the specific class of ships or resources.

2. Facilitating the up-dating of many statistical card indexes concerning the activities of the various port structures (locks, bridges, ...) and the movements of ships and resources.

3. Helping responsible authorities in the assignment of resources and in the timing of manoeuvres when the configuration of traffic reaches a certain degree of complexity.

   The conception of this aid to take a decision is based on the concept of a servicing scheme.

   A servicing scheme is a group of ships which have been selected and classified by the authorities responsible for servicing them. Applications for manoeuvring from any ship belonging to that servicing scheme will be processed methodically using an algorithm which assigns resources and departure time to every ship.

   In complex configurations the experience of responsible authorities enable them, through a preliminary rapid selection of many possible solutions, to retain a few solutions only for consideration.

   The system processes the relevant servicing schemes and visualizes the results of each of them. Responsible authorities then retain all or parts of the scheme which they find to be the best one.
DIFFERENCES BETWEEN MEAN WAITING TIMES AS A FUNCTION OF $\lambda$ AND WITH $E_0$ AS PARAMETER
1. INTRODUCTION

The dangers present in marine navigation in dense traffic zones such as the English Channel and the Straits of Dover have severely affected the international maritime trade over the past few years.

Nevertheless, these zones have always been notorious for sea accidents, such as shipwrecks, boarding and beaching. As late as a few years ago it was common to note that not only the percentage of accidents remained unchanged, but that it even showed a tendency to increase. Each accident was obviously the cause of the loss of many human lives.

But the creation of new, highly specialized ships (methane tankers), cruising at high speeds (polythene) and of ever greater size (oil tankers), some of which are veritable floating bombs linked with several spectacular accidents, has moved the maritime trade and made the public opinion in coastal countries which are most directly affected aware of the problem.

In an attempt to reduce the number of sea accidents in the straits, the Organization Maritime Consultative Intergouvernementale (O.M.C.I. - Intergovernmental Maritime Consulting Board) has recommended that a system separating traffic in the Pas de Calais be set up. This was done in 1967.

There was a slight decrease in the number of accidents at sea when recommended routes were instituted.

Unfortunately, this trend was short-lived and the number of accidents again rose. Consequently, it was necessary to carry out new studies designed to be even more effective as a navigational aid and limit the danger of collisions in this area as much as possible.
2. HISTORY

2.1. International Level

In June 1967 the O.M.C.I. adopted a traffic separation system for the Straits of Dover, first of its kind in the world. This system is based only on the goodwill of the navigators and suggests recommended traffic routes for ships, which can cruise either:

- freely in the French or British coastal waters; or
- along one-way, recommended routes.

To cut across these routes, it is advised to cross at right angles, or as near as possible. If the ship does not respect this system he is considered to be in violation.

In 1971, the O.M.C.I. recommended that the member countries consider their own ships as being in violation when navigating in the opposite direction to general traffic in the one-way routes. Consequently, the British Government included this clause in its internal legislation, as have a certain number of nations already, or plan to do so in the near future.

Traffic regulations for the Straits of Dover recommended by the O.M.C.I. should become obligatory for the new members countries in 1976.

2.2. Franco-British Level

In order to make the O.M.C.I. regulations as effective as possible, it was necessary to study the possibility of assisting navigators through this area by means of a monitoring system for marine traffic.

In June 1971, an experimental radar station was constructed in St. Margarets near Dover.

In March 1972, a similar station was built at Gris Nez.

In July 1972, an information service was established at St. Margaret's Bay for navigators transiting through the Straits of Dover.

In August 1973, a French-speaking information service was established at Gris Nez. An English-speaking service was added in early 1974. Both stations are presently fulfilling operational and experimental functions.

2.3. Operational Function

The purpose of the operation was to reduce the number of sea accidents by an acceptable percentage. Thus, radar monitoring of the Straits of Dover was set up and information is made
available to navigators in order to help them as much as possible during their transit through the straits. It should be specified that this service only provides information on a particular point and not advice on a route or a maneuver to be followed. It is impossible to state that the centers could have any responsibility for accidents now occurring in this area.

Information supplied by the stations

Data is selected according to considerations defined when we described the high accident zones, causes for these accidents and those ships which are considered as dangerous.

This data concerns:

- meteorology: only visibility is made available to navigators;
- ships in violation: all ships in violation detected by radar are listed in the bulletins, with their fix, route and approximate speed;
- ship concentration zone: only concentration zones for fishing vessels are given at present;
- large vessels or convoys which have difficulty in maneuvering: large vessels and convoys having difficulties in maneuvering must notify the Center so that their position, route and speed can be communicated to other vessels;
- other navigational hazards: all other hazards of which the Center has been notified are communicated to the navigators (burned out light buoys, buoy floating free, unsignalled wrecks, swimmer crossing the Channel, etc.).

Zone covered by Information Service

- Radio zone: given the rapid changes in maritime traffic in the Straits, it did not seem necessary to extend the radio coverage of the service excessively. Coverage of the straits and the immediate entrances seems sufficient, from Bassurelle to West Hinder.
- Radar coverage: given the performance of radar established in the stations, only data concerning an area within 24 mile radius from any one station is supplied.

3. PRESENT STUDIES

Studies presently being carried out by the various services concerned are chiefly oriented towards:

- better knowledge of traffic conditions in the Straits of
improved technological means made available to the operators, as well as means of identifying and locating ships;

- extended radar coverage of the area.

3.1. Traffic Studies

Maritime traffic in the Straits of Dover is beginning to be fairly familiar overall. However, the individual behavior of vessels, especially in certain zones such as the Sandettie region, is much less familiar.

Joint French and British studies were thus carried out, photographing the radar screens at St. Margaret's and Gris Nez and analyzing the film obtained. Studies were also made by organizing surveys of those zones not covered by radar, using specially chartered vessels.

These studies are still incomplete and should be continued throughout the next few years.

3.2. Improved Technological Means

Great responsibility is placed on radar operators in monitoring an area with traffic of 400 vessels per day, with 60 to 80 ships detected at any one minute.

This is why research was undertaken on automatic radar echo extraction and tracking in order to assist operators in evaluating traffic and the risk of possible collisions, as well as on methods used to identify vessels in the Straits.

3.2.1. Identification and location systems

The major identification and location systems considered in special studies are:

- primary and secondary radar,
- time-frequency systems,
- hyperbolic systems based on the OMEGA differential,
- satellites,
- UHF direction-finding.

Radiolocation systems were rapidly analyzed, including:

- Thomson CSF TRIDENT,
- Motorola MINIRANGER,
- Sercel SYLEDIS,
- electromagnetic cable systems,
- acoustic systems.

The two systems best suited for use in the Straits of Dover proved to be:
- direction-finding with radar monitoring and use of a computer. Given the possibility of using this system without special equipment on board, it is perfect for short-term applications;

- secondary radar which has a certain number of advantages not found in direction-finding systems. It is totally automatic and it is impossible to confuse tracks which cross. It also provides intensification of echoes detected on primary radar for peripheral zones and in the clutter. Nevertheless, the fact that it requires a special type of equipment on board makes it impossible to impose such a system internationally before at least ten years, and to have it installed on all vessels except over a rather long transition period.

3.2.2. Automatic data processing

Studies on automatic extraction and tracking systems were handled by T-VT (a subsidiary of Thomson-CSF).

Two phases were used:

- an initial phase which tested a naval EV 720 N extractor model; and,

- a second phase, presently being carried out, which tests the validity of automatic tracking.

a. Phase 1

Experiments carried out at Gris Nez on the Naval EV 720 N type extractor model were designed to prove if an automatic radar data processing system was feasible in the Straits of Dover.

Experiments were intended not only to test extractor operations but also to situate the major problems set by tracking using the MP 720 microprocessor.

The EV 720 N extractor model was connected to the present radar system at Cap Gris Nez, the basic characteristics of which are as follows:

- pulse repetition frequency (PRF) 1000 Hz
- antenna rotation 22 rpm
- pulse duration 600 ns
- antenna lobe width 0.65°
- range 24 NM approx.

The study covered the elimination of sea clutter while retaining the probability of detection generally similar to that found using raw video.
a.1. Description of installation

The various installation modules are listed below:

- radar interface
- EV 720 N model
- control display on extractor output
- test bench
- modem
- tape recorder
- PPI radar display.

a.2. Extractor operation

The various extractor modules are:

- quantification
- video interdiction
- correlation
- extraction
- output interface to Modem and IPR 14 indicator.

a.2.1. Quantification

Radar recurrence is quantified in amplitude and in range.
The quantum value is adapted to the radar range definition. The transmission impulse for the Gris-Nez radar has a width of 600 ns (which corresponds to 90 m). Coding is performed every 200 ns. The greater of the two successive samples is selected, giving a quantum of 400 ns.

The various thresholds are elaborated in this module.

The purpose of these thresholds is to indicate a presence in each quantum when the amplitude of the display coded exceeds a set value. Thresholds are elaborated to automatically adapt to sea parasite echo conditions (clutter). An initial filtering is made under these conditions. Dense clutter is eliminated while diffuse clutter is decorrelated, and thus eliminated by processing chain correlation circuits.

a.2.2. Display interdiction

As no useful datum is received from land, a display inhibition circuit is provided in those zones corresponding to the extractor input. This eliminates extractor overload by echoes which are not useful.

In the extractor model tested, this inhibition was created by using a simple angular decoding. Display is thus "forbidden" between two sectors of a particular azimuth, given the special location of Cap Gris Nez.

In the final extractor, an electronic map following the coastline will improve this function.

a.2.3. Correlation

Correlation is carried by opening a sliding azimuth gate for each quantum range. The width of this gate represents seven successive recurrences.

To do this, the six preceding recurrences are stored and when the present quantum shows, a presumption is only declared if \( x \) presences out of 7 are within the gate. For the model, \( x = 4 \).

This correlation makes it possible to eliminate the noise surge and clutter decorrelated from one recurrence to the other.

a.2.4. Extraction

Extraction makes it possible to associate, for both azimuth and range, the presumptions delivered by the correlation circuit and to set six points which define the envelope of each display, image of the echo on the screen.

a.2.5. Interface

The interface groups the data extracted and transmits it...
to the modem to enable the recording and visualization on the control PPI display.

a.3. Model testing

The first result obtained were concerned with the study of clutter and tracking. Clutter elimination is relatively good and the few parasite echos remaining are decorrelated by the following antenna sweep. They should consequently be properly eliminated by the tracking system.

Precision and discrimination tests could not be carried out for this first phase. They are planned for the prototype which has just been installed at Cap Gris Nez for phase II.

The various problems posed by tracking are evident when studying the records made.

Tracking problems will be studied in-depth on-site with the MP 720 N.

However, it should be noted that, given radar inaccuracy in range but especially in azimuth, it is impossible to use a $\chi^2$ filter. Tracking will then work by averages. The size of the various tracking gates will be precisely determined in phase II.

The MP 720 N microprocessor correlates the plots from one antenna sweep to another to create tracks. Three types of gates are thus necessary:

- initialization gate
  This gate is centered on the first plot received and must take into consideration the maximum displacement of the fastest moving vessel from one antenna rotation to the next, as well as noise and radar inaccuracy.

- tracking gate for an initialized trace
  This gate is centered on a future position calculated from the preceding positions. It is smaller than the preceding gate as vessel displacement is estimated.

- tracking gates in case of detection failure
  When there is detection failure, the future positions are still calculated but the inaccuracy of this calculation becomes increasingly greater with the number of detection losses.

Other criteria are also elaborated for starting the track. For example, there should be no successive detection losses at ini-
tialization, or there can be a certain number of detection losses over several antenna rotations. These criteria enable good clutter elimination.

Course and speed vector

These two measurements can be calculated by the MP 720 N by storing the previous vessel positions. Nevertheless, given the inaccuracy of radar and the relatively low vessel speeds, the calculation of these two factors must be carried out over a period of approximately one minute for good precision.

3.2.3. Improvement of radar characteristics

The major problems posed by automatic tracking systems are presently the result of inaccuracy in the radar used.

Plans have been made to replace this radar system by a new one which provides better performance. This radar is specially designed for maritime use by Thomson-CSF. The characteristics proposed are extremely interesting, both as concerns range and detection, as they use modern technology.

A radar system enabling monitoring of maritime traffic must have the following two basic characteristics:

- high resolution for clear discrimination of beams and maximum separation of the various echos sent back by ships;
- best possible protection from sea and rainfall parasite echos (clutter).

High resolution is obtained by using a very narrow azimuth (0.25 °) beam antenna and extremely short transmission impulses (50 ns) over the entire range. This determines an extremely small radar cell. As the equivalent clutter surface is proportional to the radar cell dimensions, clutter is consequently reduced. Frequency changes enable the decorrelation of sea clutter peaks, which should decrease this problem.

The X-band is selected so as to obtain a narrow beam, compatible with reasonable aerial dimensions. To avoid important difficulties caused by rainfall clutter from cloud illumination in altitude, the antenna site beam is narrow and inverted square of the cosecant varies up to -25 °.

The use of a magnetron with a 200 kW peak power is also an important factor in increasing range.

Under these conditions, it is possible to reach a range of 18 miles under good atmospheric conditions with an antenna located 62 m above sea level, given the following hypotheses, which are standards for Franco-British studies in the Straits of Dover.
target 25 m² with lighting point located at 3 m, 50 % detection probability and false alarm level of $10^{-5}$, radar operating on single track.

It should be noted that this range reaches at least at 15 miles for uniform rainfall of 16 mm/hr.

4. EXTENSION OF RADAR COVERAGE

The zone covered by radar systems must be extended. This is presently being done for the southwest sector, as the British authorities are installing a radar station at Dungeness with retransmission by microwave link to the St. Margaret's center. This radar station will cover a zone with an extremely high level of approaches.

In addition, the complex nature of maritime traffic in the passages going from the south tip of the Sandettie Bank to the north tip of Falls make this a crucial zone. Not only must ships having a deep draft share the passage between Sandettie and Falls with most of the vessels cruising toward the southwest, but there is also complex route crossing, including one route used by ships moving to the west and south from Belgian ports.

The extension of radar coverage to this zone is consequently completely justified, but is largely outside of the effective range of coastal installations. The construction of an automatic radar tower in this zone was therefore studied in 1974 and 1975.

The major subjects for analysis to date are:

- Ground reconnaissance in the northeast part of the Sandettie Bank;
- Definition of the various types of suitable structures;
- Reconnaissance of swell and current in the proposed zone;
- Definition of the useful nature of information provided by such a structure in the fields of meteorology, oceanography, etc.

These studies will continue in the future.

CONCLUSION

Traffic monitoring experience in the Straits of Dover carried out over the past three or four years has shown that this type of monitoring is feasible, and that it is of indisputable assistance for navigators and authorities responsible for seeing that one-way routes in this zone are respected.
This service will surely be extended in the years to come, especially by:

- the use of automatic radar data processing techniques, presently being studied at Cap Gris Nez;
- the improved performance of radar installed at the station;
- the identification of ships by radio directionfinding systems for the short-term, and using responders for the long-term;
- and the extension of the coverage zone, by the British station now being constructed at Dungeness (start-up of operations scheduled for 1976), with coverage of the Sandet-tie zone and possibly the Bassurelle zone still lacking.
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Delft University Press