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DETERMINATION OF PROBABILITY OF MARINE ACCIDENTS WITH RESPECT TO GAS CARRIERS PROCEEDING IN DUTCH COASTAL AND INLAND WATERS

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Summary

Accident and traffic data for the period 1963—1974 was used as the basis for the maritime risks involved in the coastal and port navigation of LNG carriers calling at Dutch ports. First the accident data of Rotterdam and its approaches were investigated. This area was selected because of its high traffic density and the variety of vessels calling there. As only 70 accidents had occurred, the possibilities for extensive analyses were limited. Consequently each accident was analysed in depth with regard to its circumstances and causes.

Introduction

In the near future the Netherlands is expected to supplement her own gas resources by importing Liquified Natural Gas (LNG) from abroad. The intention is to make use of LNG carriers for this purpose. The potential risks involved in the maritime transport of LNG for both local population and the environment need to be considered.

To assess these risks the Dutch Institute for Applied Physical Research (TNO) was consulted. The Netherlands Maritime Institute (NMI) was in turn requested to carry out the maritime risk analysis associated with the coastal and port navigational aspects.

This paper deals with the maritime risk analyses carried out by the NMI.

Determination of the probabilities of grounding and collisions

In June 1974 the Dutch Ministry of Social Affairs requested the Dutch Institute of Applied Physical Research (TNO) and the Netherlands Maritime Institute (NMI) to determine the risks which could be associated with the importation of LNG into the Netherlands. This request was based upon the assumption that after 1980 the local gas resources would be insufficient. Therefore LNG would have to be imported. However, the possibility exists that an accident involving an LNG-carrier could occur and it was therefore necessary to determine the probability of such an accident and its possible consequences. Following this request a research project was started in which the NMI was to determine the probabilities of grounding and collision in the suggested landing areas. TNO was to determine the probabilities of other types of accidents involving the transfer and storage plant and was also to carry out the combined risk analysis, i.e. calculate, for all foreseeable accidents, the product of various probabilities and consequences. In this paper we deal with the NMI-contribution.

On reading the files on accidents involving vessels near the Dutch coast and looking at the damages sustained, one certainly cannot conclude that a collision or grounding of such a magnitude that an LNG-spill would occur is impossible.

However, when analysing general data, it has to be kept in mind that manoeuvring and construction characteristics of the LNG-carrier are in quite a few respects completely different from the great majority of vessels calling at Dutch ports. The main differences between an LNG-carrier and a vessel of comparable size are:

(a) Smaller draught which enables them to proceed in coastal areas where comparable vessels could run aground;

(b) Smaller draught/depth ratio which gives them a large wind surface. This in turn can cause extra difficulties when manoeuvring in confined areas in conditions of strong winds;

(c) More enginepower per ton deadweight which affects a number of manoeuvring characteristics in a favourable way and can cause a reduction in grounding and collision probabilities. However, as regards collision probabilities this is partly offset by a greater chance of being hit in the vulnerable side when the turning capabilities are over-estimated and the vessel does not succeed in turning away from an imminent collision;

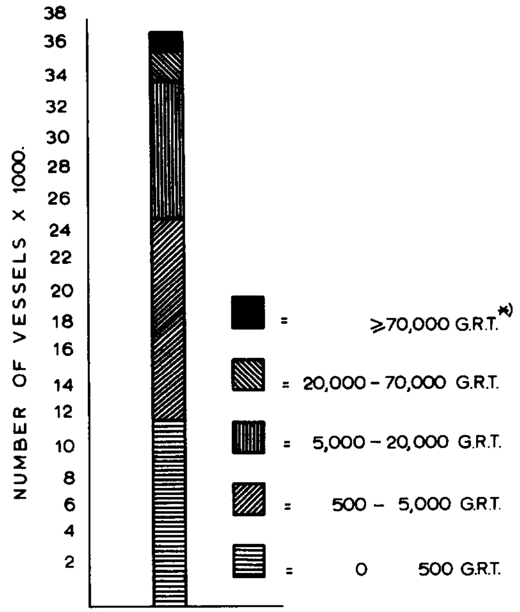
(d) A double hull serving as an extra barrier in case of collision or grounding.

The effects of (b) and (c) are difficult to judge because the human factor plays a vital role. Moreover the probability of collision in particular is also affected by the quality of crews of the other traffic participants. The lower end of the spectrum of possible crew qualities is illustrated by a paper prepared by two doctors on diseases which they found in crew members on vessels calling at Dutch ports.

> "Kabir Ahmed from India: tuberculosis, Stanley Peireira from Cape Verde: kidney cancer in an advanced state, Koesprianto from Indonesia: completely blind, Maniatakia from Greece: syphilis in the third phase.
>
> It is difficult to imagine how one gets a collection of people suffering from these diseases. They would be totally unfit to work. However, in fact, they were crew members of a vessel which was in such a bad state that it should already have been broken up."

On other similar vessels the doctors met patients suffering from other diseases which the western world believes to belong to history like small pox, typhus, leprosy etc. At the other end of the spectrum we find vessels operated by companies doing their utmost to maintain the qualities of their ships and crews at a high and safe level.

Another handicap was that even for a port like Rotterdam the number of movements of vessels having dimensions more or less similar to an LNG-carrier are relatively small. (See Fig.1.) Moreover the present situation at the Hook of Holland exists only since 1971, so data from before 1971 had to be treated with extra care.



*) G.R.T. = Gross Register Ton = 100 cubic feet

Fig. 1. Traffic of merchant vessels calling at Rotterdam (1974).

With this in mind it was decided to investigate the 12-year period 1963—1974 in a thorough manner and examine all accidents reported in the Hook of Holland approaches and the harbour entrance. (Fig.2). When carrying out this rather tedious job we tried to determine whether the risk pattern of the total vessel traffic could be considered relevant, in part or in total, for the LNG-carrier.

The harbour basins were not closely examined for accident data, because from the start it appeared that numerous collisions happen there, which are, however, seldom of sufficient magnitude to cause heavy damage. Moreover, based upon the vessel speeds in the harbour basins and the strict traffic regulation which already exists for large vessels in the harbour basins where the LNG-carrier would discharge its cargo, the probability of a heavy collision

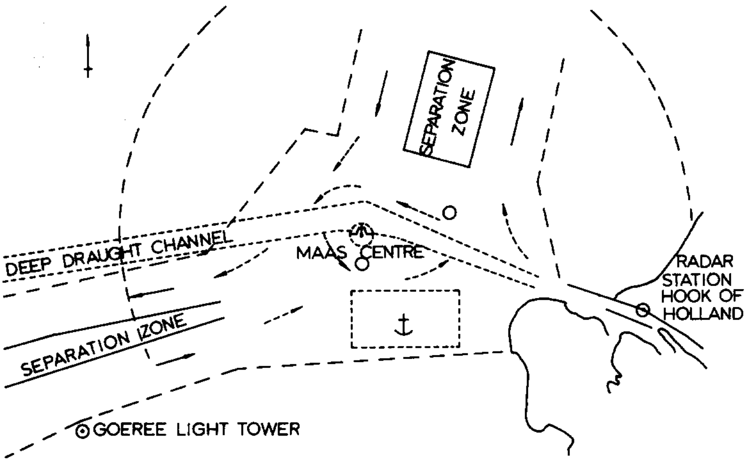


Fig. 2. Traffic flow scheme in the approaches to the Hook of Holland.

there could be considered negligible compared with the probability of such a collision at or near the river entrance.

When collecting accident data it appeared that it was necessary to do this "at the sources" that is, to collect these data from the authorities which register the accidents on the spot such as river police, harbour authority, etc.. The reasons for this were:

(a) Not all reports on collisions, etc. are forwarded to the central recording authority (Shipping Inspection), because many of them are not considered interesting or severe enough. This could be perfectly true, but for our investigation every accident was at least interesting.

(b) Some accident reports which had been forwarded disappeared in the administrative mill.

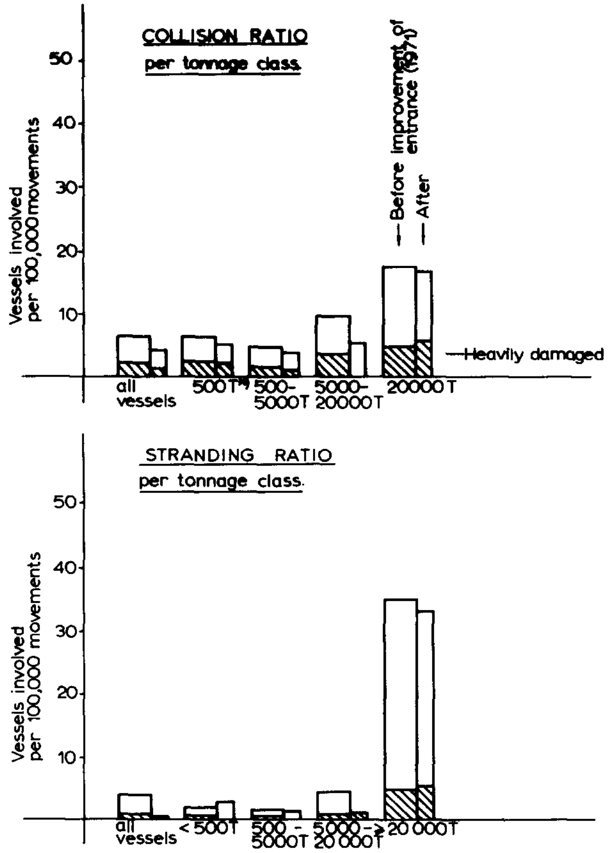
(c) When recording the accident stories at for example the local river police station, a lot of extra information on what actually happens in the area is gathered from the stories told by people who work in the area every day.

When an accident inventory had been compiled it appeared that during the 12-year period investigated only 33 collisions and 34 groundings had occurred involving only 6 vessels of sizes similar to the LNG-carrier. The total number of vessel movements in the same period was about 850.000 (merchant vessels only). All but one of the collisions were caused by errors of the human operator on the bridge whilst about 67% of the groundings were due to this type of error. The remaining accidents were caused by technical failure. Whether this in turn was caused by a human operator in the engine room remains an open question.

During bad visibility (< 1500 m) navigational procedures and traffic pattern are different from the ones under normal conditions. Therefore collisions and groundings were divided according to visibility conditions, rendering 17 collisions and 28 groundings in good visibility and 16 collisions and 6 groundings in bad visibility. Because in bad visibility tankers are not allowed to proceed when landward of the anchorage, the accidents which occurred in bad visibility are hardly relevant. It should, however, be pointed out that the collisions in bad visibility made up 50% of the total number of collisions and occurred in a condition which exists for only about 4% of the time. This indicates a considerable higher probability of collision in bad visibility.

The total number of collisions is evenly spread over daylight and night conditions. However, if we discard the collisions in bad visibility we see that during the night the collision ratio (meaning the number of vessels involved in collision divided by the number of vessel movements) is about 5 times higher than during the day, whilst traffic densities are more or less equal. A similar phenomenon was found in other areas and also by other researchers. Also, the grounding ratio during the night was higher than that during the day.

When we looked at the collision and grounding ratios for vessels of different tonnage classes it was found that the bigger vessels had higher accident



*) T = Gross Register Ton = 100 cubic feet

Fig. 3. Collision and stranding ratios.

ratios during good visibility as well as during bad visibility. This is shown in Fig.3. Moreover the bigger vessels showed less improvement in accident ratio after the completion of the improvements to the river entrance. When looking at collisions only it was found that for large vessels the collision ratio for incoming vessels compared unfavourably with outgoing ones.

The next problem was to determine what vessel size boundaries should be adopted in order to define a group of vessels which could be considered as being more or less similar to an LNG-carrier as well as comprising enough vessels to render at least some data for comparison with other size classes. Eventually the group of vessels bigger than 20,000 Gross Register Tons was considered to be most suitable, because this group was reasonably large (40,000 movements in 12 years) and consisted of vessels which, as regards manoeuvring characteristics, compared more or less favourably with the LNG-carrier. The number of vessels in this group which were involved in collision was 6 and the number of vessels grounded was 14. These figures are so small that they are unsuitable for further methods of analysis which deal with numbers only. We now describe how the collision data were treated and analysed.

The 6 vessels involved in collision showed the following pattern:

(a) of the vessels involved 5 were incoming and 1 outgoing.

(b) all but one became involved because of an error of the counter party.

(c) there was hardly any difference in accident ratio between the period before the improvement to the river entrance and the period thereafter.

However, the whole group of vessels involved in collision in good visibility was evenly spread over incoming and outgoing vessels, and the improvement of the river entrance coincided with an improvement in collision ratio for this group. The question was whether the phenomena mentioned under (a), (b) and (c) above should be given any weight when determining the probability

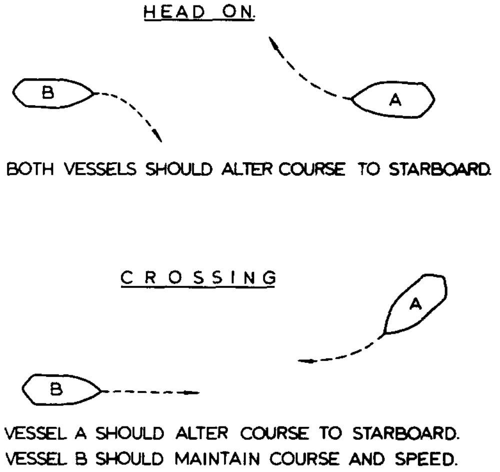


Fig. 4. Head-on and crossing rules.

of a collision or should they be ascribed to coincidence. Eventually it was decided to give full weight to the phenomena mentioned under (a), (b) and (c). This was done after consideration of the traffic pattern, the accident pattern, the pattern of accident causes and the rules of the road.

Let us first recall some of these rules of the road (Fig.4).
In the situation shown in the top half of this figure, both vessels should alter course to starboard. In the situation shown below, vessel A should give way and vessel B should maintain course and speed. If vessel A neglects her duty vessel B should give way when convinced that a manoeuvre by vessel A alone is not sufficient to avoid a collision.

Let us now look at the situation near Hook of Holland (Figure 5). In this phase a collision situation may develop when one of the vessels gets on the wrong side of the leading lights, and thus the incoming vessel can get involved in a collision in one of two ways:

(a) because of his own error

(b) because of an error of the outgoing vessel

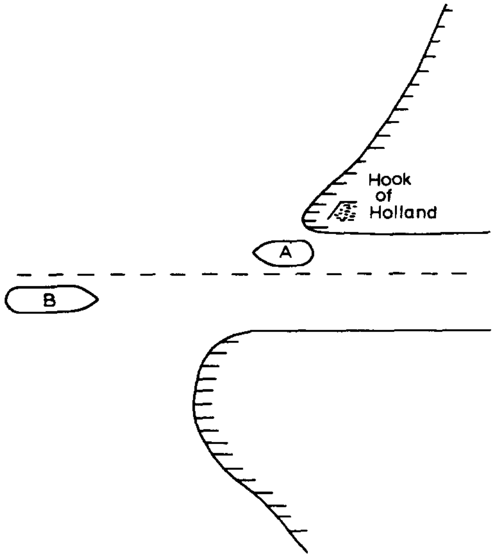


Fig. 5. Situation near the Hook of Holland.

(a) The incoming vessel gets involved because of his own error

Because the intention of the incoming vessel is to follow the leading lights and get inside the entrance, this vessel will in most cases be at small angles with the leading lights even if it unintentionally crosses the line. In this case the head-on situation will develop in which both vessels must give way. Also, conditions are clearly more demanding for the incomer, who will thus be more alert and more liable to detect an emergency situation and take action.

Generally speaking, it appeared that the occurrence of this type of collision decreased after the improvement of the river entrance, both in conditions of good visibility as well as bad visibility.

(b) The incoming vessel gets involved because of the error of an outgoing vessel

After passing the piers the great majority of outgoing vessels have plenty of searoom to starboard so that a correction necessary to stay on the correct side of the leading lights is limited by neither physical boundaries nor the traffic pattern, because most meetings are head-on or with conflicting traffic on the starboard side. Therefore, these vessels will seldom cross the leading line because of an error or even because of negligence, but mostly on purpose.

Now for outgoing vessels the pilot station lies north of the leading line, so for them there will be little reason to go to the wrong side before they have disembarked the pilot. For unpiloted ships and ships which have already disembarked the pilot it is often attractive to cross the leading line as soon as possible and shape course for their destination, which is often more or less to the south west. In this case the leading line will be crossed at larger angles. If this behaviour leads to a conflict situation it will often be of the kind shown in the lower half of Fig.4. There is a fair chance that these outgoing vessels do not keep a proper look out because:

(i) the conditions are less demanding

(ii) the peak of outgoing traffic falls in the late afternoon when deck officers often have a busy day behind them and have night watches ahead, so the tendency exists to send them below as soon as possible.

(iii) The pilot is not (or no longer) on board so the quality of watch-keeping depends completely on the vessels' crew and this quality can be well below average.

In this situation the incoming vessel must delay his actions until the other one alone cannot prevent a collision. This means that most of the time it will be too late when the outgoing vessel is much smaller than the incoming one. Especially for vessels bigger than 20,000 GRT the chance of meeting a much smaller one is considerable because about 70% of the traffic is smaller than 5000 GRT.

When outgoing, one has the advantage of having plenty of searoom to starboard so that the leading line can be kept at a comfortable distance. Also there are few incoming vessels which cross the leading line at considerable angles. Consequently the collision risk for outgoing vessels is more dependent on their own qualities and less on that of other traffic.

To summarize: the conclusion is that in good visibility especially, large incoming ships are vulnerable to becoming involved in collisions which are caused by improper watch-keeping of smaller outgoing ones which are not (or no longer) under a pilot's direction.

The occurrence of collisions caused in this way is hardly affected by shore side improvements. Therefore it was also concluded that, in accordance with

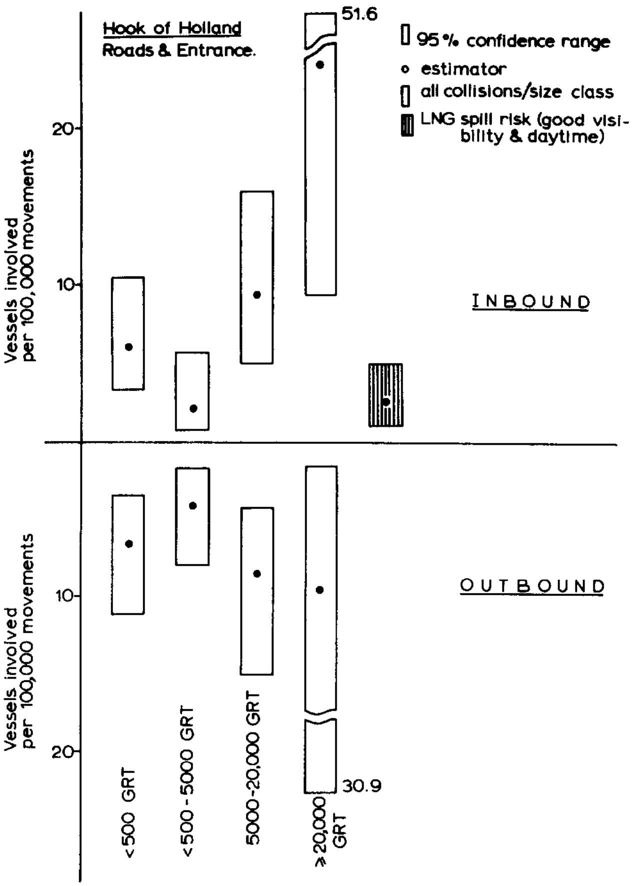


Fig. 6. Collision probabilities.

the scarce data, there was no reason to expect any improvement for this type of accidents. The end result is given in Fig.6, which shows the estimators and 95% reliability interval for collisions in good visibility in daylight.

As regards grounding data a superficial glance gave the impression that there was also no improvement for this type of accident. However, a closer examination showed that:

(a) some vessels involved were deepdraught tankers which ran aground well outside the area where an LNG tanker could touch the bottom. If these vessels were disregarded there was an improvement.

(b) Larger vessels in particular grounded due to technical failures, a type of failure which is also hardly affected by shore-side improvements.

(c) Considering groundings caused by operating errors of the navigator only there was also an improvement.

Based on the phenomena just described and on the knowledge that vessels operating under poor technical management in particular are vulnerable to accidents due to technical failure, whilst it can be expected that LNG-carriers which have to maintain a rather strict schedule will be more conscientiously operated and maintained, it was concluded that an improvement in grounding risk could be expected.

There is not enough space here to discuss the other two possible areas for the importation of LNG into the Netherlands. It can, however, be stated that a totally different approach was necessary for these, because of the scarcity of accident data which also could hardly be considered of any relevance since nearly all vessels involved were much smaller than an LNG-carrier. In particular the Delfzijl Eemshaven required special judgement techniques, because the fairway has an estuary character. Factors to be considered were, for examample: fairway width; fairway depth; fairway bends; fairway current; and accuracy of navigational means available. These factors naturally had to be judged in combination. Recently the fairway configuration has undergone some favourable changes causing several of the findings of the original report to be obsolete.

Determination of accident probabilities for inland waterways

Shortly after the LNG-project was completed, the NMI and TNO-organization were requested to determine the risks associated with the transportation in bulk of LPG and other liquified gases. These commodities are also transported on inland waterways, which cover large distances and often have intensive traffic volumes. This implied that huge amounts of accident data had to be handled so that reliance on the capabilities of a computer was necessary. Existing accident registration schemes were in general inadequate to provide the data for automatic data processing. Therefore it was decided to design a registration form and a coding which included the many different conditions and causes of accident occurrences and which could be used to provide an answer to the various questions posed during the research. For completion of the form, an alpha-numerical coding was chosen using codes which looked familiar to persons with a nautical background. Care was also taken to use as far as possible the same scales and sub-divisions as used in the original accident reports. Describing the whole scheme in detail would take too much space, and so only the broad outlines are given below.

Data contained in accident reports can be divided in two main categories:

(i) details about the vessels involved and the accident conditions, for example: vessel tonnage, whether or not pilot on board, visibility, etc.

(ii) accident causes, for example: bad look-out, technical failure, etc.

Care has to be taken to keep these two categories separated, as the latter especially is sensitive to subjective interpretations. For example, the running aground of vessels in a river bend could be attributed to pilot's error. However, when quite a number of vessels run aground there, it could be worthwile to look at the accident conditions again and one may find that a certain combination of vessel size and current direction renders many groundings. This could lead to a completely different appraisal of the accident causes. Now if accident conditions are not registered in such detail as to specify, for example, current direction, such a re-appraisal would be impossible. Moreover, the registration of accident conditions requires less time than determining its causes, for which it is necessary to read and evaluate the whole accident story. Therefore the columns containing the conditions are all placed together in such a manner that they can be completed first. The condition columns contain data such as time of accident, weather conditions, vessel data, whether piloted or not, and voyage phase: such as moored, throughgoing, entering main fairway, etc., and also extent and location of damage. Quite often the data regarding damage was very inaccurate. Therefore we added a column "Damage class", which could be entered with the numbers zero to four, "zero" meaning little or no damage and "four" meaning large holes, vessel broken into two, etc.

By describing accident conditions in detail we were able to obtain an answer to questions such as "How many self-propelled inland tankers were involved in collision in winter time in good visibility ($\geqslant$ 1500 m)?" or "How are collisions divided between head-on, crossing and overtaking categories?" or "How many vessels were heavily damaged between fore and aft bulk heads because of a collision in bad visibility?" etc.

Setting up the scheme for registration of the accident causes was a time-consuming job as there were many possible combinations. We adhered however, to the following guidelines:

(a) If several causes of an accident together form a chain in which each cause is the inevitable result of the former one, only the cause which initiated the chain is stated. The reason for this is that by stating all the elements of such a chain, one could get a completely wrong impression of the error or causes pattern. For example, an accident caused by drunkenness of the driver could be described in the following way: (i) driver drunk; (ii) wrong interpretation of traffic lights by driver; (iii) wrong operation of braking pedal after driver realized he was wrong. It is clear that only the first cause should be stated.

(b) The navigator is considered the central element to whom all information is passed and who takes all final decisions.

(c) The reasons for technical trouble were not entered into in detail as in most accident files they are not stated.

Subsequently the elements constituting the process of navigation and ship handling were analysed and systematically grouped. This was used as the basis upon which accident causes were categorized, and resulted in the sub-division shown in Table 1. Each sub-division is often again sub-divided in columns; for example, "not obtaining sufficient data, with respect to own vector" can be subdivided into: visual; own radar; radio; compass, log; etc. In each column a character can be entered which indicates what part of the systhem actually caused the error (for example pilot, technical failure, helmsman, etc.)

TABLE 1

Extract of marine accident registration form

Main division		Sub-division
(A)	Structural shortcoming of vessel and/or crew shortcoming (example: sub-standard crew)	(a) crew (b) engine (c) radar etc.
(B)	Not obtaining sufficient data (example: poor look-out)	(a) with respect to own vector (b) with respect to other traffic etc.
(C)	Insufficient data available (example: unreported shoal)	(a) with respect to own vector (b) with respect to other traffic
(D)	Misreading of available information (example: misreading course)	(a) with respect to own vector (b) with respect to other traffic
(E)	Not providing sufficient information to others (example: not showing navigation lights)	(a) with respect to own vector (b) with respect to own configuration (c) with respect to own intentions
(F)	Wrong assessment of situation (example: under-estimating speed of other vessel in crossing situation on inland waterways)	(a) with respect to own vector (b) with respect to other traffic
(G)	Wrong handling of vessel	(a) turning (b) stopping (c) wind (d) current
(H)	Planned action not carried out (example: helmsman turns wheel in wrong direction, or engine failure)	(a) engine (b) rudder (c) assisting tugs (d) mooring gear etc.
(I)	Wilfully ignoring directions given by authorities	
(J)	Act of God (Lightning, meteorites, etc.)	

All data are later entered onto punch cards and subsequently fed into the computer. The system has been used now for registration of about 4000 accidents, which happened on various types of waterways, and only small alterations were necessary. Moreover, an answer could be given to all sorts of questions arising during the risk analysis.

Let us now consider some of the main findings of the risk analysis carried out for the New Rotterdam Waterway area. As we were interested in spill risk it was not sufficient to look only at the total number of accidents of a certain type, but we also had to look at the resulting damages. On the other hand looking only at heavy accidents would render very little data making it impossible to determine differences in risk for various weather conditions, etc. Therefore the term "damage ratio" was introduced, meaning the ratio between the number of vessels heavily damaged in a certain type of accident and the total number of vessels involved. Thus we could use the total number of vessels involved to determine the overall collision grounding risk etc. under various conditions. Thereafter the damage ratio was applied to determine the actual spill risk.

It appeared that for inland waters only collisions provided a real spill risk. The number of other accidents and also their damage ratio was much smaller so that in comparison with collisions the spill risk of the other accidents could be neglected. This statement can, however, only be considered valid if no cargo treatment or cleaning or repair activities are carried out. This is a limitation based on consideration of the accidents which happened to the Marpessa, King Haakon and other vessels. Also it was found that seagoing vessels proceeding under pilot's direction are about 10 times less likely to cause an accident than unpiloted ones.

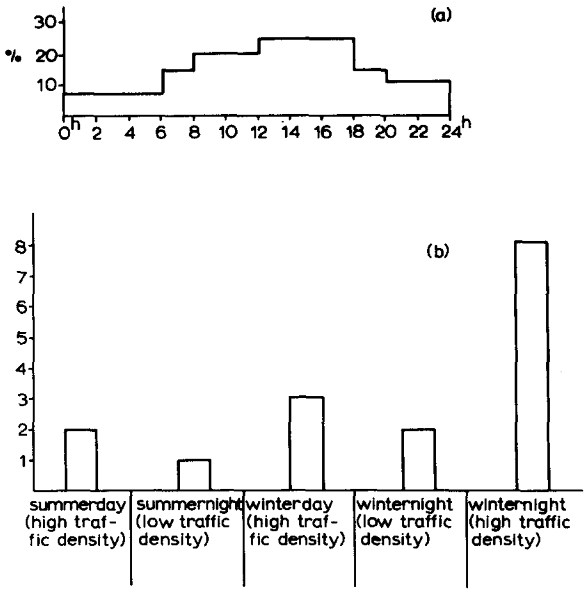
As regards seagoing vessels it appeared that only collisions between these vessels constituted a spill risk. Thus when predicting the spill risk for seagoing vessels, only the collisions involving other seagoing vessels had to be considered. Again fog and darkness proved to cause higher collision risks, but so also did strong winds, which even rendered a collision ratio about 20 times higher than the average. Again it was found that as regards seagoing vessels, the accident ratio increases with increasing tonnage. Fig.7a gives the distribution of vessel movements over twenty four hours, and Fig.7b shows the collision ratios for inland vessels under various conditions relative to the condition which has the lowest ratio and which has been given index 1. No absolute figures can be given because these are not yet free for publication.

We give below some general rules to be followed when determining the nautical risk for a certain area.

[1] Start by studying charts, pilots, meteorological data, etc. of the area to be investigated.

[2] Find out which authorities compile accident data in the area and arrange interviews with them. Quite often they give you a lot of valuable additional information. Arrange these interviews so as to obtain an impression of the amount and quality of the accident data. Try to find out how these data are forwarded to other authorities and how they are filed. Quite often this is done in a way which is the only practical one but which deviates from the official one.

[3] Find out which authorities compile traffic data and arrange interviews



(Lowest collision ratio has been given index 1)

Fig. 7. (a) Distribution of vessel movements over 24 hrs. (b) Relative collision ratio.

for the same reasons as mentioned under [2]. It is important to have traffic data available in an early stage, because they may also determine the way in which you register accident data. If, for example, a certain area has very few different types of vessel traffic, it makes little sense to devise an elaborate sub-division of vessel involved in accidents according to vessel type.

[4] Arrange interviews with people frequently working in the area: pilots, harbour police, etc., to find out about their ideas regarding accident proneness, traffic behaviour, etc.

[5] Check on definitions used by different authorities and if possible compare their data. Sometimes certain expressions have different meanings with different authorities, and there can also be considerable differences amongst data as compiled by different authorities.

[6] It is of great importance that the researcher himself reads at least 10 per cent of the accident reports and tries to do so at the offices of the authorities which register the accidents. The reason is that it is impossible to devise an accident registration code which also contains the accident *stories*. However, the accident stories also provide considerable data about traffic behaviour. Moreover, when spending some days at the office of the authorities one establishes very valuable unofficial contacts which also provide much additional information. In short, it fills in the details of the traffic and accident data.

[7] When analysing accident and traffic data, plotting them on graphs with respect to time, weather conditions, geographical location and vessel type or size class, can be of great help. The sub-division used in these graphs should

be as fine as possible to enable you to detect trends. For example, when plotting with respect to time do not use seasons or four-hour periods, but use hours and weeks or when plotting with respect to vessel size, do not use size classes but use actual vessel tonnage.

Conclusions (with respect to the areas investigated only)

(i) In the port areas and port approaches large seagoing vessels, when proceeding under conditions of good visibility, run a greater risk of collision or grounding in comparison with smaller ones.

(ii) In the port areas and port approaches the collision risk in fog or during hours of darkness is considerably higher in comparison with good visibility and daylight in similar traffic densities.

(iii) In the port areas collision risk in strong winds is considerably higher in comparison with conditions of moderate winds and similar traffic densities.

(iv) Vessels proceeding under a pilot's direction are about 10 times less likely to cause an accident than vessels not under a pilot's direction.