Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 41 (1983)

Artikel: Marine traffic flows with reference to fixed offshore structures
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DOI: https://doi.org/10.5169/seals-31654

Marine Traffic Flows with Reference to Fixed Offshore Structures

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Seeverkehr und befestigte Bauten im offenen Meer

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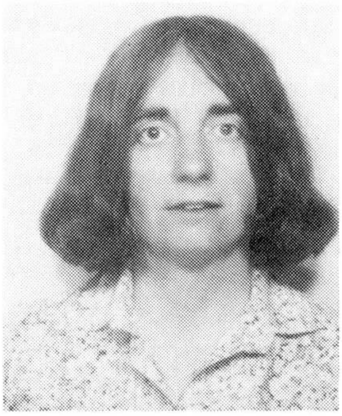

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SUMMARY
This paper gives an overview of various aspects of marine traffic flows. The aquisition of data is discussed, followed by an account of various useful parameters which can be measured or evaluated in a study of marine traffic flows.

RÉSUMÉ
Cette étude présente une vue générale de quelques aspects de mouvement de la circulation maritime. On discute comment les données sont acquises, et ceci est suivi d'une explication de quelques paramètres utiles qui peuvent être mesurés ou évalués dans une étude de mouvement de la circulation maritime.

ZUSAMMENFASSUNG
Dieses Referat bietet einen Uberblick über verschiedene Aspekte von Bewegungen des Schiffsverkehrs. Das Sammeln der Daten wird erörtert, und darauf folgt ein Bericht über verschiedene nützliche Parameter, die bei einer Untersuchung von Bewegungen des Seeverkehrs gemeßen oder ausgewertet werden können.

1. INTRODUCTION

The study of marine traffic flows is still a relatively new area of concern. The work in Europe on this topic began seriously about the beginning of the 1970s although the Japanese had been pioneers in the work a few years before. For many centuries the principle of the freedom of the sea and in particular the freedom of navigation was recognised universally but various developments have caused people to question it closely. The increasing size of ships especially those used to transport cargoes such as oil, chemicals and liquid natural gas is one factor since various incidents have led to a growing awareness of the human and ecological consequences of even a minor accident at sea. Another aspect has been the continual economic demands for optimal efficient use of sea transport. However one of the most important factors has been the increasing tendency for structures to be built in the sea. The expansion in offshore resource exploration has resulted in considerable numbers of offshore structures being built all over the world and in European waters especially. Often these structures are in areas such as the North Sea where the available navigable sea-room was already restricted especially for the modern deeper-draught ships. Advances in engineering have resulted in bridges being built or planned in areas often of high shipping density with the effect again of reducing the available navigable sea-room. Single structures are being erected often for communication purposes. The presence of any structure in the sea is a potential hazard to shipping navigating in its vicinity and hence it is of importance to those responsible for placing the structure,those responsible for the safe navigation of vessels and society in general that the risks of accidents should be minimised. It has therefore become widely recognised that since conditions at sea are changing good information is needed on the behaviour of marine traffic under different circumstances. Until about ten years ago in Europe very little was known on marine traffic flows but now the position has changed considerably and it can now be hoped that any decisions affecting marine traffic navigation may be made causing the minimum of disruption to all parties concerned. This paper is concerned with the development of the study of marine traffic flows referring especially to the question of flows past fixed offshore structures.

2. ACQUISITION OF MARINE TRAFFIC FLOW DATA

2.1. General Considerations

The first stage in any traffic flow investigation must be the collection of suitable data. The primary considerations concerning the acquisition of this marine traffic flow data must be firstly the purpose for which the data are required, secondly the cost of acquiring it and thirdly the time scale over which it is required. In many areas little is known even about the daily volume of traffic passing through the region and if information only on a macro level such as this is required then relatively simple methods of data acquisition can be used. At the opposite extreme data are required on the exact positions of individual ships as they pass through an area and for this sort of information on a micro level complex methods of data recording are required.

2.2. General Traffic Density Surveys

Lloyd's Intelligence Service will supply a rough indication of the density of various types of merchant ship traffic passing through an area which is based on reported ship movements. A recent example of this for the Norwegian fixed offshore platforms in the North Sea is given in a paper by Skjong and Laheld [1]. No figures are however given for fishing vessels or traffic servicing an area such as oil rig supply ships, and so these figures must be obtained from other sources.

Another method used in a recent paper by Lewison [2] was to use the archive of reports from voluntary weather reporting ships. These ships regularly give their positions and meteorological reports which are compiled into a large data file held by one of nine meteorological offices round the world. The UK office for example holds data for the area 40^{o}- 70^{o}N, 20^{o}W - 10^{o}E and it is possible to obtain the numbers of reports in different areas. There are widely differing opinions as to how representative the sample obtained this way is. For instance, there will probably be an underrepresentation of fishing vessels and there may also be inconsistencies in reporting so that some ships report more frequently than others. It is felt that particularly in heavy traffic density areas there may be a decrease in reporting because the ships' officers are too busy concentrating on the problems of navigating. However Lewison argues that the picture obtained gives very good values for relative traffic densities. It is thus possible to estimate the traffic density in a previously unsurveyed area based on the traffic density in another area for which better information is available.

A more direct approach for ascertaining traffic densities in any area is the use of aircraft to fly over the designated area. This method has been used frequently by the National Maritime Institute either using specially charted commercial aircraft or planes of the RAF on training flights. Two typical examples of this approach are given in the reports of studies undertaken to estimate the risk of collision between ships and offshore structures for the Forties Field [3] and the Western approaches to the English Channel [4]. The NMI were able to arrange for the RAF to route several training flights over the particular region needed for the study. Photographs of the radar were taken during the flight and then the positions of vessels observed were plotted on charts and hence density distributions can be obtained. This method gives more direct information on location of ships within the given area although information on complete ship tracks is not usually available.

A fourth approach is that used by the Netherlands Maritime Institute [5] when they did a survey of ship routes in the North Sea and Dover Strait in 1977. Questionnaires were filled in by ships' masters as they entered and left each port around the North Sea and Dover Strait over a certain period of time. From this information a variety of ships' routes throughout the area were defined and a likely daily traffic volume assigned to each. Ships' officers and pilots who frequented the routes were asked to describe the likely course that a vessel on the route would take and as a result it was possible to plot the likely courses on a large chart of the area. It was then possible to locate points of convergence of routes and hence points of potential high traffic density. Typical speeds on routes were also estimated.

All these three methods are fairly expensive to use but most important of all provide only general background information on likely traffic densities. For instance in the fourth method which perhaps gives the most detailed information no knowledge is gained about the behaviour of traffic on the routes such as the lateral separation of vessels. They are perhaps useful for giving an indication of the likely overall traffic density in an area of interest.

2.3. Surveys of Marine Traffic Behaviour

Goodwin and Kemp in 1977 conducted a reasonably low cost survey of marine traffic in the Southern North Sea, an account of which has previously been published [6]. The purpose of this survey was to investigate the use ships made of available sea room and thus to establish whether ships tended to keep to a self-imposed routing structure when passing through a particular area and if so how wide were the routes. Other questions of interest might be the distribution of ships across the routes and the speeds throughout the area.

The survey was conducted from the m.v. 'Sir John Cass', research vessel of the City of London Polytechnic. The ship is mainly used for radar training in the Thames and has three radar screens for this purpose. It was thus possible to use one for survey work without hindering the navigation of the ship in any way. Ships' tracks were plotted directly from the radar PPI onto transparent sheets placed over a reflection plotter on the radar display itself. Direct plotting has the advantage that less subsequent processing of the data is needed and a further advantage is that any close encounter situation can be sorted out as it arises and lessens the chance of tracking ambiguities. However the method is only really suitable in areas of relatively light traffic density and when there is sufficient manpower available. This particular survey at the Sunk was conducted for a total of 20 hours over two days and in this period 94 ships giving an average of nearly 5 per hour were observed. The method can also be useful if the closest passing distance to a fixed structure is required. The area surveyed by Goodwin and Kemp contained two fixed objects, an old war time fort, the Roughs Tower and the Sunk lightvessel. The table below taken from a paper on collision risks for fixed off-shore structures by the same authors shows for ships passing within two nautical miles of each object the percentage having closest passing distances within each range.

Table 1 Closest passing distances for ships passing Roughs Tower and Sunk Lightvessel.

Closest Passing Distance (nautical miles)	Roughs Tower %	Sunk Lightvessel %
0 - < .25	16	25
.25 - < .5	5	20
.5 - < .75	16	16
.75 - <1	26	13
1 - <1.25	14	3
1.25 - <1.5	16	9
1.5 - <1.75	0	3
1.75 - <2	7	11
Number of ships	43	56

The nature of the area was such that there were more routes passing the Sunk lightvessel than the Roughs Tower and additionally some ships needed to take on a pilot from the pilot cutter which cruised near the lightvessel. However the figures did suggest that there is a tendency for ships to pass closer to objects which are navigation marks than ones which are not, which in turn could affect the collision rate adversely for structures which are navigation marks.

The survey described above used direct plotting of ships' tracks for recording information. However in areas of higher traffic density or situations where there is less manpower available then the next simplest alternative is photography of the P.P.I. An advantage of the method is that all the targets in an area are captured simultaneously on a photograph whereas if the targets are plotted manually there is a spread of time as they are plotted in turn. The main disadvantage is that the photographs then have to be analysed to obtain ships' tracks and problems can arise in sorting out close quarter situations. Photography or the direct output of the information from an ARPA might help in this. Several researchers have used this method for different studies among them Goodwin [8] and Coldwell [9] both of whom took photographs manually at 3 minute intervals. This enabled visual watch to be kept simultaneously for ship identification and general background information such as changes in visibility. Goodwin used a stationary ship based radar and Coldwell a shore based radar. Experience with moving ship based radar for a particular area has been that interpretation of other ships' tracks in the area is not easy over a period of time. Kwik and Stecher [10] have done some work from the bridge of a ship on a voyage from N.W. Europe to the Persian Gulf using an automatic movie camera to record the radar display. Their main results have been concerned with the movement of other ships relative to their own ship rather than relative to fixed objects. In the NMI study in the Forties field [3] photographs were taken of the radar on board one of the support vessels, to obtain a detailed picture of the traffic pattern around the installations in the oil field.

The Japanese who were the undoubted pioneers in the marine traffic survey area have used some interesting methods of time lapse photography to obtain ships tracks [11]. They have also used purely visual observation for surveys but this is only possible when the geography of the area permits overview of narrow waterways. This method is well suited for counting the number of ships crossing a given datum line and the ships can be identified in many instances by name as well as by type and length. However in poor visibility which is often one of the most critical conditions for marine traffic identification and even counting can become almost impossible. It is also difficult to estimate the range of passing from the observation point and speed is another parameter which cannot be estimated easily.

An example of another approach to detailed real-life marine traffic flow information is the completely automatic data acquisition system based on Digiplot used in the Hook of Holland Roads Survey [12]. The radar information is fed directly into a computer for processing, but there were often problems of tracking individual ships when ships pass close to each other particularly if they manoeuvre at the same time. Identification of ships is another problem. The positions of all ships in the survey area were recorded in the Rotterdam survey at 15 second intervals but even with this data frequency considerable work had to be done to sort out the individual tracks in the high traffic density in this area. There are likely to be more advances in the automatic acquisition of data but there are considerable costs attached at present in terms of both the hardware and software needed.

The preceeding discussion has attempted to cover most of the major approaches to real-life marine traffic surveys which have been used in recent years when information about the behaviour of ships travelling through a given area is required. Although there have been some advances recently a more detailed account of the relative advantages and disadvantages of the different methods for real-life traffic surveys was given by Kemp and Holmes in a paper published in 1977 [13].

Real-life traffic surveys give authentic information but they have various disadvantages as well.

- They are expensive no matter which data collection method is used. The expense may be limited if the data are collected from a shore based station which perhaps only collects data as a secondary function. For instance the Channel Navigation Information Service [14] based near Dover produces a continuous record of marine traffic movements through the Dover Strait but there is still a need for subsequent processing. Many areas however can only be surveyed from a ship present in the area.
- Real-life surveys can be very time consuming. In the work done by the Marine Traffic Research Unit in London using the m.v. 'Sir John Cass' for data collection, a considerable proportion of time was spent in getting the ship to and from the appropriate spot. Additionally there is no guarantee that all the allotted time for a survey of this sort will produce useful results. If one were trying to study situations under which particular types of manoeuvres were made one might have to wait several hours between occurences. There is also the very real risk that bad weather could cause abandonment of the survey anyway.

- There may be situations under which the collection of results could be at the worst hazardous and even at the best create problems because the survey ship is itself creating another obstacle which may affect the behaviour of other ships.
- Extraneous variation is another problem. It is not possible to control the majority of variables in a situation so that those which are of interest may be influenced by changes in those which are not. For example changes in weather conditions may make one day's survey results incompatible with those from another day.
- It is often not possible to monitor all the variables in which one is interested. Thus identification of all ships in the survey area may be difficult and hence it is impossible to get full statistics on type or size of ship.

2.4. Data from Marine Radar Simulators

An alternative method of data collection is to observe the performance of navigators on marine radar simulators. This is very suitable as a means of studying the behaviour of mariners under different traffic flow problems such as navigation through an area which contains a bridge or fixed structures. Most nautical colleges have marine radar simulators for training mariners for navigation in fog when there is no chance of a visual lookout so considerable reliance has to be put on interpretation of the radar picture. Different situations can be replicated on the radar screen and it provides a valuable means of training mariners. The recent development of ship handling simulators with optical or television presentation of the view from the ship's bridge in addition to radar and other instrumental simulation increases the possibilities of research and training but at present there are not many available and it is quite a complicated task to change the scenario the mariner is faced with.

Changes of scenario on a radar simulator are comparatively more straightforward and several research projects have been carried out this way. Goodwin [8] in 1975 published a study on ship domains which will be discussed later in this paper, the data for which were collected from real-life surveys and from observations of the marine radar simulator at the City of London Polytechnic. The exercises which navigators do on this simulator are all of the discovery type, so that no briefing is given to the mariners before they undertake the exercise and all discussion is carried on afterwards. Thus mariners are not repeating actions they have been told to do only fifteen minutes earlier but are having to rely on their own sea-experience. This helps in ensuring fidelity which is the main worry over using the simulator. The navigator must be aware that he is in a simulated situation rather than in a real-life one and as a result may react in a different fashion. Ideally if one is using a simulator to give practice in a particular task then all features of the real situation which influence performances of that task should be represented. This includes features which may be detrimental to performance as well as those which assist it. A radar simulator may be made realistic in so far as the radar display may be exactly the same as those used on board ship but there is still a question as to whether this is sufficient or not. The simulation of a bridge at sea is one of the most difficult situations to achieve with a satisfactory amount of realism since there is not only the physical layout of the bridge which is needed but also the movement of the ship. Even the smell of salt may affect performance! In addition to these physical features the psychological features of stress and anxiety are difficult to simulate in any situation. The main stresses that arise are firstly those due to operating in a potentially dangerous environment, secondly the threat of hazards or sanctions if a wrong decision is made and thirdly time stresses. Since little is known about the effects of these stresses most researchers have concentrated on the validation of simulator results with those obtained in real-life surveys. The ship domain results mentioned earlier suggested reasonable correspondence between the two data sources and this result was echoed in a study by Holmes [15] on the distances at which navigators first initiated manoeuvres. However in both of these studies the real-life data were collected in good visibility. A paper by Curtis and Barratt [16] in 1981 compared data from a radar display of the Dover Strait under thick fog conditions with data from a radar training simulator. They chose to compare the parameter of passing-track separation for ships in overtaking situations and again on this parameter reasonable agreement was found.

In addition to overcoming many of the disadvantages of real-life surveys suggested above there is one major advantage of using marine radar simulators which should be stressed. This is that standard situations can be produced in which all the variables of interest can be controlled and measured to within very close limits. These situations can then be replicated as often as required and hence it can be a very efficient means of data collection.

2.5. Mathematical Models

Another useful way of examining marine traffic problems is by the development of mathematical models. They can be extremely useful if one wishes to consider the effect of changing different parameters in a situation and one requires a reasonably quick answer. Models may be either analytical or digital depending on the degree of sophistication required. One of the earliest of these was built by Draper and Bennett [17] (1972) and was concerned with traffic flow in the Dover Strait under different routeing systems. If one is interested in considering possible changes then there must be an objective measure for the end result of any changes. In this study the encounter rate between ships was taken as such a measure, an encounter being recorded when two ships passed within half a nautical mile of each other. All mathematical models however need information on marine traffic flows and it is not always possible to assume that results on the behaviour of ships in one area can be transposed to apply for another area. There is also the problem that once a model is altered to evaluate the effects of a change in traffic patterns, it has to be assumed that all other parameters stay constant. However in real-life this may not be true.

The modelling approach and the radar simulator can both be used however to examine experimental suggestions, whereas it is a very difficult and time consuming business to experiment at sea itself.

Degre and Lefevre [18] have built a computer simulation model for traffic in the English Channel and the results from this have been used as a basis for discussions for further routeing schemes in the English Channel. Another large scale model which has been used as a basis for determining optimal traffic organisation schemes in the Hook of Holland Roads has been built by the Netherlands Maritime Institute in conjunction with the Royal Shell Laboratories Amsterdam and has been described in a paper by Spaargaren Tresfon [19]. The objective criterion used in this model for distinguishing between different alternative traffic schemes is described in a paper by Van der Tak and Spaans [20]. The criterion they develop gives recognition to such elements as traffic density, course and speed distribution of the traffic and the danger classes of the ships participating in the traffic, this latter being a special feature of this particular measure. Thus it is possible to assess the effect of keeping certain ships separate from the main traffic flow.

At Plymouth Polytechnic researchers there are building computer models which will simulate the manoeuvres of a ship with respect to land such as coastlines and narrow channels. An account of this model is given in a series of papers by Davis, Dove and Stockel [21], [22] and it clearly has applications when considering flows past fixed structures, or under bridges.

2.6. Questionnaire Methods

For the sake of completeness brief mention should be made of another means of obtaining information on the behaviour of marine traffic and that is by the use of questionnaires. They obviously provide a cheap method of collecting factual data but there may be problems in practice which can lead to biased results unless care is taken. Limited experiments at the City of London Polytechnic suggested that questionnaire replies on matters concerning the performance of navigators at sea tend to reflect what navigators would do in idealised situations and often bear little relationship to what is done in practice. However Davis, Dove and Stockel [21] in the work mentioned above used questionnaires for determining from mariners likely closest points of approach under different situations as an input for their model. However it was necessary to validate the results from real-life studies performed by other people so great care had to be taken with the results. Questionnaires are perhaps more suitable for obtaining factual information such as equipment on board or routeing patterns as determined by the Netherlands Maritime Institute in 1977 [5]. The main problem here is ensuring a reasonable rate of return of the questionnaires and that bias does not creep in because the non-response is all from one type of ship say.

3. USEFUL PARAMETERS OF MARINE TRAFFIC FLOWS

3.1. Typical Parameters

The previous section has attempted to describe the major methods used for data acquisition and at the same time has described many of the parameters which are of interest. Some of the more important ones are general traffic density, size and type of ships, speed distribution, arrival and departure distributions from an area, routeing patterns and lateral distributions across routes, and manoeuvre behaviour between two ships or one ship and a fixed obstacle. As mentioned in the section on modelling the study of an area is usually concerned with the measurement of risk to shipping existing in the area and this is perhaps the most important secondary parameter to be estimated from the study. The second part of this paper will therefore be concerned with this measurement of risk.

3.2. Encounter Rates

Most of the work in marine traffic flows has been concerned with the measurement of collision risk between two moving vessels. A collision is usually the result of a variety of circumstances and it is often the combination of several factors in the final stages of the event that result in the accident. Much work is going on into the determination of these factors notably by authors such as Kemp [23], Cockcroft [24] Drager [25]. Some of the factors are essentially human factors which are very difficult to monitor and yet others can be characterised as mechanical breakdowns. Although a collision with a fixed structure involves one moving ship only it is clear that many of the basic principles of investigation and analysis for collisions between ships will be useful in the former case.

It has long been considered that a reduction in the collision rate might be helped if a reduction in the encounter rate for ships could be achieved. This has long been a principle in the air in the maintenance of air separation standards, typical papers on this being those by Reich in 1964 [26] & [27]. Lewison [28] in 1978 investigated the relationship between encounter rate and collision rate for marine traffic in the Dover Strait, but there are always problems in making inferences based on numbers of collisions because they are relatively so rare. The numbers of encounters in an area do obviously give an indication of the average number of potentially complicated incidents a navigator is likely to experience in any particular area.

An encounter may be said to have occurred when two ships come within a specified distance of each other. However if the measure is to be meaningful as well as objective then the choice of specified distance is very important. One approach is to use a fairly arbitrary encounter distance such as 0.5 n.miles as taken by Barratt [29] (1973) in his work on encounter rates in the Dover Strait. An encounter between two ships under this definition is said to have occurred if a second ship enters a circle of radius 0.5 n.miles centred on the first ship. A different choice of radius such as 0.4 n.miles would produce different results. This may not matter too much if one is comparing the situation in a given area under different traffic organisational schemes but is not very satisfactory if one is looking at comparisons between areas. The major disadvantage is however that the choice is not based specifically on a navigator's own behaviour and if at a later stage it is hoped to persuade navigators to accept decisions based on measures of encounter rate then realism is important. The second approach therefore for the choice of encounter distance is to base it on ship domain theory.

3.3. Ship Domain Theory

A ship domain may be thought of as the effective area around a ship which a navigator would like to keep free with respect to other ships and stationary objects. This particular definition was proposed by Goodwin [8] (1975) and was developed from some initial work of Fujii and Tanaka [11] in Japan. The work by Goodwin has been extensively used in open sea situations but in 1982 Coldwell [9] extended the theory to narrow channel situations.

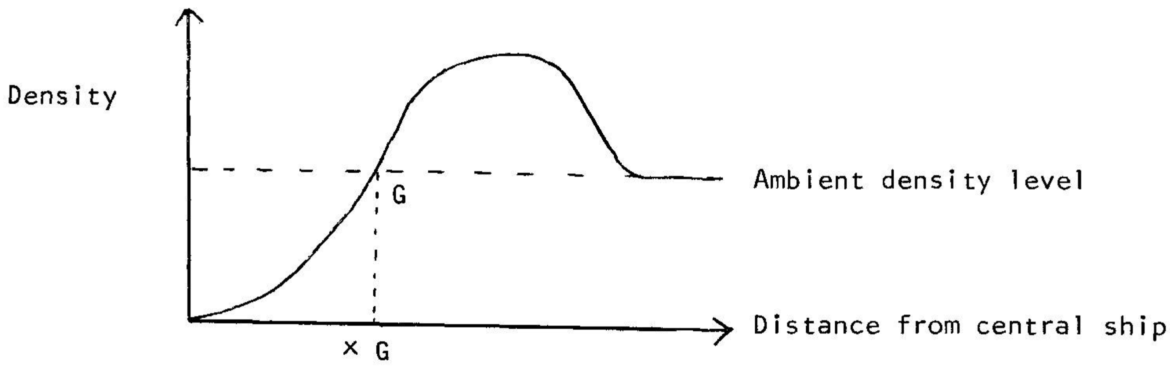

Fig. 1 shows a typical curve obtained if one were to plot the density of shipping around a central ship against the distance from the central ship. In the immediate vicinity of the central ship there are hardly any if any other ships, but as the distance increases from the central ship the density rises and then falls again until the overall density level of the area is reached. This is because ships take action if necessary to avoid coming too close to another ship. In practice one would not obtain the diagram illustrated in Fig. 1 at any one point in time but it can be built up by superimposing a succession of time points and also a succession of different ships. Authors vary as to the definition of the domain boundary but Goodwin has taken point G in the diagram, the point at which the density curve first reaches the ambient density level. It was possible to establish a straightforward objective method of locating the domain boundary and results were obtained for a number of different factors that it was felt might influence the size and shape of the domain such as speed, size of ships, traffic density etc. Data sets from both the marine radar simulator and real-life surveys in the Southern North Sea described earlier in this paper were used to determine the results and these are given in Table 2.

Table 2 : Domain boundaries in Nautical Miles for different Sea Areas by Sector

Sea Area	Sector 1	Sector 2	Sector 3
Simulator data : Dover Strait	0.8	0.8	0.1
Simulator data : Gibraltar Strait	1.5	1.4	0.6
Simulator data : Open Ocean	2.4	2.4	0.9
Survey data : S.North Sea	0.9	0.7	0.5
Survey data : Hook of Holland Roads	0.3	0.3	0.3
Survey data : S.North Sea, buoys	Circle radius 0.1 n.mile.		

At sea the responsibility for collision avoidance depends on the relative bearing of two ships, hence the domain boundary was evaluated separately for different sectors. Taking the direction of motion of the central ship and measuring an angle θ clockwise from this line then Sector 1 is defined as $0 \leqslant \theta \leqslant 112.5$ (starboard bow), Sector 2 as $247.5 \leqslant \theta < 360^{\circ}$ (port bow) and Sector 3 as $112.5 < \theta < 247.5$ (astern). The Hook of Holland Roads results also given were evaluated in a separate study reported by Goodwin in 1978 [30] but were based on the data set described by Van den Hoed [12], already mentioned.

It is also possible to define a domain around a stationary object such as a buoy or fixed structure. In Fig. 1 the stationary object would be placed i the position of the central ship and tracks of ships with respect to it analysed. The survey in the Southern North Sea suggested that a circular area of radius 0.1 m.miles around a buoy is the area of clear water which navigators of a typical ship like to keep free. As a buoy has no motion of its own it is not surprising that the results are much smaller than for two ship encounters. The domain of a fixed structure is likely to be larger than that for a buoy, but may also depend probably on traffic density where the domain for a buoy has been shown to be fairly constant in different traffic areas. Fujii [31] 1977 has also postulated the existence of a hard core domain which represents the lowest limits to which a ship domain can be compressed. Evidence for this in further work by Goodwin suggests that the circular area of 0.3 n.miles found in the Hook of Holland Roads may represent average dimensions for a hard core domain for typical shipping ir North West European Waters.

Abdelgalil [32] has approached the definition of a domain from the hydrodynamic effects of being close to other ships or structures and this i obviously another useful approach.

Having established the size and shape of a domain it is possible to use it the basis of a definition of an encounter. The navigator would consider himself to be in an encounter situation if there was another ship in his domain or if his ship encroached the domain of a fixed structure.

The use of a domain as a basis for encounter rates has been adopted in the various models described earlier by Degre and Lefevre [18] and Davis, Dove and Stockel [21], [22]. In the work by Van der Tak and Spaans instead of using average domain sizes for an area, different domains for different dai classes of ship have been calculated. This might also be a useful approacl in work on fixed structures as size of ship is very important in potential impacts, but also the overall consequences of an accident involving an LNG carrier or passenger ship are far greater than one involving say a general cargo ship. The economic consequences of accidents to different types of ships is being studied at present by Giriakis, another member of the Marin Traffic Research Unit and analyses of this will be available soon.

3.4. Weighted Encounter Indices

Various authors are working on suitable indices to establish the level of danger in any area. Goodwin [30] in 1978 developed an Index of Orderliness which counted future encounters as well as actual encounters with a decrease in weighting depending on the period ahead for the potential encounters.

The maritime risk criterion number of Van der Tak and Spaans [20] has already been mentioned. Another approach whereby the number of actual encroachments of the domain were related to the number of potential encroachments was described in a paper by Goodwin & Loh [33] (1981). Lamb, working under the auspices of the Marine Traffic Research Unit is developing this work much further and has defined an index based on the manoeuvres needed to avoid a collision.

Another approach is that of Lewison [2] who has developed a Fog and Collision Risk Index using data from voluntary reporting ships as described earlier. The weighting of encounter rates by external factors such as visibility is obviously another interesting idea. This has been used in a study of the Forties Field by the National Maritime Institute [3].

All of these measures have been developed for the ship-ship collision situation to provide comparisons between different areas. It would be fairly straightforward to adopt them for the ship-fixed structure collision situation and thus enable relative risks for existing and planned structures to be evaluated.

3.5. Related Work

As a concluding section it is perhaps worth summarising briefly some of the alternative approaches to obtaining estimates of collision risks for fixed structures which have been used by some of the authors mentioned throughout this paper as a development of the work on marine traffic flows. Lewison [34] (1978) gives four methods in a paper on the North Sea Offshore Installations. These are (i) use of domain infringement, (ii) comparison with ship collision rates, (iii) infringements of safety zone around installation and (iv) comparison with collision rate with other fixed objects. Goodwin and Kemp [7] (1980) have also used similar methods to Lewison's (i) and (iv) but have used another method based on the probability of groundings. Barratt[4] (1981) has used the final three of Lewison's methods for estimating potential collision risk in the English Channel and the Western Approaches.

4. CONCLUSIONS

This paper is intended as an introduction to some of the navigational aspects of ship collisions with fixed structures. There are however many navigational aspects which are outside the scope of this particular paper, such as the provision of equipment on the bridge of the ship.

The paper falls into two main sections. Firstly an attempt has been made to discuss the variety of methods which have developed over the last ten years for the collection of data on marine traffic flows. It has not been possible to give a completely comprehensive account but the intention has been to illustrate the work of some of the main research groups in this area. The second part is concerned with the analysis of these data and again the intention has been to illustrate some of the ideas which have been discussed over the past few years which could be used to investigate further the problem of ship collision with bridges and offshore structures.

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