A study into maritime collision probability

L.A. Pimontel BSc
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Cover photograph:

Collision between the LPG gas carrier M/T Gas Roman (55 000 DWT) and the timber carrier M/V Springbok (15 000 DWT) on Thursday 27th February 2003 in the approach to the Port of Singapore

A study into maritime collision probability

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering, specialisation Hydraulic Engineering

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PREFACE

This Master Thesis forms the completion of my education at the Delft University of Technology, Faculty of Civil Engineering and Geosciences, Department of Hydraulic Engineering. The research was carried out at Royal Haskoning in London.

In this report possible factors of influence on maritime collision probability have been investigated by carrying out a statistical analysis of incident data as well as analysing AIS images. Finally, the reliability of the Royal Haskoning maritime traffic simulation program MARTRAM was investigated.

I would like to thank the members of my graduation committee, Prof. ir. H. Ligteringen, ir. R. Groenveld and Prof. dr. K.A. Brookhuis of the Delft University of Technology and R.J. Hennessy of Royal Haskoning for their support and feedback during the past months.

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And finally, a big thank you to all my colleagues at Royal Haskoning London for making my time at the office so enjoyable and thanks to my family and friends in The Netherlands who continued to support me throughout my stay in the UK.

Lisette Pimontel
London, March 2007
ABSTRACT

At present the maritime transport sector is responsible for approximately 90 per cent of global trade and it continues to grow. As with every mode of transport there are hazards connected to maritime transport, the most evident hazard being collisions between vessels. In the light of port design, capacity studies and maritime risk assessments, it is desirable to be able to quantitatively determine the maritime collision risk for restricted waters. Maritime collision risk is defined as the collision probability multiplied by the consequence of a collision. But finding this maritime collision risk is not as straightforward as this formula might lead to expect. The prediction of possible consequences of a collision is a very complex matter. Also, no method exists with which the collision probability between vessels underway in restricted waters can be quantitatively determined with sufficient accuracy. The main reason for this is that the collision probability is influenced by factors such as the traffic situation and also by the behaviour of the human beings operating the vessels, but so far these influences have not been quantified.

In absence of such a quantitative method for determining collision probability, a qualitative approach to assessing maritime safety in restricted waters can be used. A generally accepted approach is to simulate the vessel traffic in a specific situation using a so-called maritime traffic simulation program. Such a computer program simulates the flow of vessels along navigation channels. Each vessel is assigned a vessel safety domain, which may not overlap with the vessel safety domains of other vessels. This undesirable overlap of vessel safety domains is called an encounter. During a simulation run, the maritime traffic simulation program counts the number of encounters. This number can then be used as a measure to compare the relative safety of different alternative designs. It cannot be used to quantify the collision probability as the relationship between an encounter and the collision probability is yet unknown. However if incident data is available of the specific location under consideration, a relationship between the number of encounters and the number of collisions can be derived against which the simulation results can be calibrated. An important disadvantage of this encounter method is the fact that no universal definition exists for these vessel safety domains and their dimensions.

Before maritime traffic simulation models will be capable of quantifying the collision probability between vessels in restricted water it is necessary to obtain more insight into the factors which influence this collision probability. This thesis describes two investigations that were carried out to this end.

The first of these was a statistical investigation into maritime incident data. An attempt was made to identify which factors have the greatest influence on the probability of a collision between vessels in restricted waterways. Two incident databases were considered: the PLACID database of the Port of London Authority and the SOS database of the Dutch Ministry of Transport, Public Works and Water Management. The investigation was based on the assumption that a high representation of certain factors in these incident databases implies that these factors played a role in the occurrence of the incident and therefore have a significant influence on the collision probability. From both data sources it appeared that the vessel type and assumed collision cause had the clearest influence on the collision probability between vessels. However the vessel types that were most likely to be involved in an incident were differed for both areas. Human errors were found to be the most frequent cause of incidents in both incident databases, however more research was recommended to investigate possible relationships between various incident causes. It also appeared that most incidents occurred in normal weather conditions such as daylight, good visibility and calm weather.
The conclusions based on incident data are location specific, and further investigation is required to indicate whether these conclusions are also valid in other situations.

The second investigation consisted of a study into maritime traffic in the Port of London approaches based on four days of traffic data. This data was obtained from an Automatic Identification System (AIS) on board a survey vessel. The aim of this investigation was to learn which factors have the greatest influence on the Closest Point of Approach (CPA) between vessels underway in restricted waters. This knowledge is valuable for the process of understanding navigational behaviour and defining vessel safety domains for restricted waters.

Using the programs FoxPro and MapInfo, eight encounter situations between vessels were identified. An analysis of these encounters demonstrated that most encounters occurred in overtaking traffic situations rather than in meeting or crossing situations, and that tanker vessels were most frequently involved in encounter situations. This was possibly caused by the large vessel safety domain used for tanker vessels. No relationships were found between the vessel type and the CPA, the vessel dimensions and the CPA or the vessel speed and the CPA. A comparison of the CPA and the available channel width showed that many vessels did not use the entire available channel width. This implies that the captains of the vessels involved were comfortable navigating so close to one another. Finally, it was observed that the method of vessel safety domains for defining encounter situations is not capable of taking into account the fact that in restricted waters, vessels are frequently required to navigate close to one another without necessarily creating a hazardous situation. It is essential to develop vessel safety domains specifically for restricted waters.

A recommendation was also made to continue this study using more traffic data and to also consider the situations moments before the actual encounters occurred. This will provide insight into the point at which encounter avoiding manoeuvres are initiated and possibly also into suitable dimensions for vessel safety domains in restricted waterways.

In the final section of this thesis the reliability of an existing maritime traffic simulation program called MARTRAM was evaluated. MARTRAM uses the method of encounters to determine the relative safety of a traffic situation. This program was previously used for a risk assessment of the Port of London approaches, therefore a model of this area was readily available. The AIS traffic data of this same area was used as input for the program and simulation runs were carried out after which the MARTRAM results were compared to the AIS data.

It appeared that significantly more encounters occurred in the simulation than in reality. This difference was caused by simplifications made in the model and restrictions of the program, most importantly the limited ability of MARTRAM to model encounter avoidance behaviour. Human beings play a large part in the avoidance of encounters as they are able to anticipate hazardous situations and carry out timely avoidance manoeuvres. It is not yet possible to simulate this behaviour using a computer program.

A large variation was also apparent in the number of encounters that occurred during the different simulation runs. Therefore it was not possible to identify a single ratio between the number of AIS encounters and the number of MARTRAM encounters. This was desirable as this ratio could have aided in the calibration of the model of the Port of London approaches. These results confirm that MARTRAM is not suitable for the quantitative analysis of maritime safety. But MARTRAM can be used for the relative analysis of maritime safety, in which case it is recommended to develop the program so that it includes more possibilities in terms of collision avoidance behaviour. It was also recommended to decrease the level of variations in the program in order to obtain a more uniform output.
CONTENTS

PREFACE I

ABSTRACT II

LIST OF FIGURES VI

LIST OF TABLES VII

1 INTRODUCTION 1
   1.1 Problem introduction 1
   1.2 Problem analysis 2
      1.2.1 Problem definition 2
      1.2.2 Research objective 2
   1.3 Report outline 3

2 MARITIME SAFETY ASSESSMENT 4
   2.1 Introduction 4
   2.2 Maritime transport 4
   2.3 Maritime risk assessment methods 6
   2.4 Maritime simulation programs 8
   2.5 Vessel safety domains 10
   2.6 Studies into collision probability 15
   2.7 Chapter conclusions 20

3 MARITIME INCIDENT DATA 21
   3.1 Introduction 21
   3.2 Data sources 21
   3.3 Data analysis 23
      3.3.1 PLACID analysis 24
      3.3.2 SOS analysis 29
   3.4 Chapter conclusions 37

4 STUDY OF MARITIME TRAFFIC 40
   4.1 Introduction 40
   4.2 Automatic Identification System (AIS) 40
   4.3 Port of London approaches 41
   4.4 Analysis of AIS traffic data 42
      4.4.1 Encounter situations 43
      4.4.2 Other situations 50
   4.5 Chapter conclusions 53

5 MARITIME TRAFFIC SIMULATION PROGRAM 55
   5.1 Introduction 55
   5.2 MARTRAM 55
   5.3 Model of Port of London Approaches 58
   5.4 Model input 59
   5.5 MARTRAM evaluation 60
   5.6 Chapter conclusions 65
LIST OF FIGURES

Figure 1-1, Report outline 3
Figure 2-1, World seaborne trade 1970-2005 4
Figure 2-2, Sea-going merchant vessels in world fleet 2006 5
Figure 2-3, Flowchart of FSA methodology 7
Figure 2-4, Risk factors affecting port and waterway safety 8
Figure 2-5, Five main steps in PAWSA process 8
Figure 2-6, Vessel safety domains for a vessel with length of approx. 100 metres 11
Figure 2-7, Domain boundary suggested by the relative tracks of other ships during a crossing of the English Channel 12
Figure 2-8, Schematic distribution of ships around a central ship 13
Figure 2-9, Definition of vessel safety domains for restricted water 14
Figure 2-10, Definition of crossing angles 18
Figure 3-1, Vessel types involved in collision (PLACID) 25
Figure 3-2, Vessel types involved in near misses (PLACID) 25
Figure 3-3, Port of London traffic data and near miss statistics 26
Figure 3-4, Pilotage situation for vessels involved in collisions (PLACID) 27
Figure 3-5, Pilotage situation for vessels involved in near misses (PLACID) 27
Figure 3-6, Port of London approach channels - Locations of collisions (PLACID) 28
Figure 3-7, Port of London approach channels - Locations of near misses (PLACID) 29
Figure 3-8, Vessel categories involved in collisions (SOS) 30
Figure 3-9, Inland merchant vessel types involved in collisions (SOS) 31
Figure 3-10, Port of Rotterdam traffic data and collision statistics of sea-going merchant vessels 33
Figure 3-11, Bathtub curve 34
Figure 3-12, Assumed main incident categories (SOS) 36
Figure 4-1, Admiralty chart 1607, Thames Estuary Southern part 41
Figure 4-2, Vessel tracks through Port of London approaches 42
Figure 4-3, Vessel with vessel safety domain 42
Figure 4-4, Encounter locations in Port of London approaches 43
Figure 4-5, Definition of various traffic situations 44
Figure 4-6, Encounter 1 (Sunnanav and Argisilaos, 13-11-2006) 44
Figure 4-7, Encounters 2 and 3 (Britta Oden and Dart4, 14-11-2006) 45
Figure 4-8, Various encounters at the entrance to the Princes Channel (14-11-2006) 45
Figure 4-9, Encounter 7 (Betty Theresa and Dart 9, 16-11-2006) 46
Figure 4-10, Encounter 8 (Monsoon and Sigas Commander, 16-11-2006) 46
Figure 4-11, Vessel types, lengths and CPA’s 48
Figure 4-12, Vessel types, widths and CPA’s 48
Figure 4-13, Encounter CPA’s and Channel widths 49
Figure 4-14, Available channel width and CPA’s 49
Figure 4-15, Vessel types, vessel speed and CPA’s 50
Figure 4-16, Dart 9 and Samskip Courier (13-11-2006) 51
Figure 4-17, Sand Weaver, Dart 3 and Forth Fisher (14-11-2006) 51
Figure 4-18, Britta Oden and Dart 4 in Eastern Princes Channel (14-11-2006) 52
Figure 4-19, Britta Oden and Dart 4 in Western Princes Channel and Oaze (14-11-2006) 52
Figure 4-20, Anette Theresa and Hoo Falcon in Western Princes Channel 52
Figure 5-1, MARTRAM Vessel properties input screen 56
Figure 5-2, MARTRAM Route properties input screen 57
Figure 5-3, MARTRAM Lane discipline 57
Figure 5-4, Screenshot of an encounter in MARTRAM 58
LIST OF TABLES

Table 2-1, Ranking of influences on collision probability based on interviews | 19
Table 3-1, Sources of maritime incident data | 23
Table 3-2, Vessel types involved in incidents and their pilotage situation (PLACID) | 25
Table 3-3, Traffic data for the Port of London, 28-07-2004 to 14-12-2004 | 26
Table 3-4, Assumed incident causes (PLACID) | 28
Table 3-5, Vessel types involved in collisions (SOS) | 31
Table 3-6, Port of Rotterdam traffic data (January-December 2005) and collision statistics of sea-going merchant vessels | 32
Table 3-7, Light conditions and collisions (SOS) | 33
Table 3-8, Visibility conditions and collisions (SOS) | 34
Table 3-9, Current speeds and collisions (SOS) | 34
Table 3-10a, Wind speed conditions and collisions (SOS) | 35
Table 3-10b, Frequency table of wind speeds, Hoek van Holland, 1971 – 2000 | 35
Table 3-11, Assumed main incident causes (SOS) | 36
Table 4-1, Summary of encounter situations | 43
Table 4-2, Traffic through Port of London approaches, 13-11-2006 to 16-11-2006 | 47
Table 5-1, MARTRAM encounter results | 61
Table 5-2, Comparison of MARTRAM and AIS encounters | 62
Table 5-3, Vessel types involved in MARTRAM encounters | 64
1 INTRODUCTION

1.1 Problem introduction

In the transport business, safety and efficiency are key issues. These are not always compatible; a greater speed or higher traffic intensity usually means higher efficiency but lower safety. An optimum balance needs to be found between the transport efficiency on one hand and the safety on the other hand. Every transport branch has its own possible hazards, as well as its own methods of evaluating their effects on safety. Also, different measures are available to minimise the probability of such hazards occurring and to minimise their consequences in case they do occur.

According to COLWILL et al., (2004): 'In busy ports around the world the hazard profile is dominated by ship-ship collisions'. Consequences of a collision can be damage to the vessel or its load, foundering of the vessel, environmental damage, human injury or possibly even fatality. Various measures to improve the safety in maritime transport have been implemented in areas of restricted water such as port areas and their approach channels. Examples of such measures are the marking of navigation channels using buoys, improved radar and other navigational equipment on board vessels, the introduction of internationally recognised Collision Regulations (COLREGs), VTS assistance and most recently the introduction of the Automatic Identification System (AIS). All of these measures have caused an improvement in the maritime transport safety, but the exact measure of this improvement is unknown. In fact, no method exists with which the maritime transport safety in restricted waters can be quantified with sufficient accuracy.

Although maritime transport safety cannot be quantified accurately, it can be evaluated qualitatively. One way of doing so is to investigate maritime accident statistics of collisions or near misses between vessels. Such statistics can provide various insights, for example about vessel types that are more likely to be involved in an accident than others. The disadvantage of this approach is that it requires an extensive amount of detailed accident data, which is often not readily available.

Another way to qualitatively assess the maritime transport safety is to estimate the collision probabilities in certain areas. A generally accepted approach to analysing vessel-vessel collisions in restricted waterways is to simulate the vessel traffic through a specific area using a so-called maritime traffic simulation program. In such a program the vessels are modelled to pass along the navigation channels while external influences such as winds, currents and the presence of other vessels are only modelled in a very simple manner or are not included in the program at all.

During a simulation, each time two vessels come within a set distance to one another, the program registers this as an “encounter”. An encounter is an undesirable event. When two vessels come close to one another, the probability of a collision increases. It is not yet possible to determine a precise value for this collision probability as this depends on a great number of factors, for example the weather and the capability and behaviour of the captain.

Current maritime traffic simulation programs are not yet capable of accurately modelling such things. But by comparing the number of encounters occurring in different situations, conclusions can be made regarding the relative safety of various channel designs and port layouts.
Before it will be possible to accurately quantify the safety of a maritime traffic situation, much more research will have to be done. This thesis contains research done into the various factors that influence the collision probability between vessels in restricted waterways. Hopefully these results will prove to be a step in the direction of quantifying maritime traffic safety.

In the following paragraph the problem definition and the research objectives of this thesis are given. Paragraph 1.3 gives an outline of the set up of rest of this report.

1.2 Problem analysis

1.2.1 Problem definition

At present no method exists with which the collision probability between vessels underway in restricted waterways can be quantitatively determined with sufficient accuracy. More research is required on the topic of collision probability in order to aid in the development of such a method.

1.2.2 Research objective

The objective of this thesis is to obtain more insight into the collision probability between vessels underway in restricted waterways, especially into the various factors influencing this probability. As the Closest Point of Approach between vessels is closely related to the collision probability, this concept will also be researched. Finally, this thesis aims to evaluate the reliability of an existing maritime traffic simulation program.

The following questions have been defined to structure the research:

- Which factors have the greatest influence on the probability of a collision between vessels underway in restricted waters?\(^1\)

- Which factors have the greatest influence on the Closest Point of Approach between vessels underway in restricted waters?

- What is the reliability of MARTRAM, the maritime traffic simulation program used by Royal Haskoning to qualitatively analyse maritime safety in restricted waters using the method of encounters?

---

1 The research in this thesis is restricted to vessels underway. This excludes berthed vessels, vessels at anchor and manoeuvring vessels.

2 The term restricted waterways indicates water areas in which the navigation of vessels can be influenced by the geometry of the available water. The vessels are restricted in their possibilities to carry out collision avoidance manoeuvres.

March 2007
1.3 Report outline

Figure 1-1 below illustrates the set-up of this thesis. The contents of each chapter is briefly described, and the locations of the answers to the research questions are indicated.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Contents</th>
<th>Answer to research question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1</td>
<td>Introduction</td>
<td>General information concerning maritime transport and existing maritime safety assessment methods</td>
</tr>
<tr>
<td>Chapter 2</td>
<td>Maritime Safety Assessment</td>
<td>Investigation of maritime incident statistics</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Maritime incident data</td>
<td>Analysis of maritime traffic based on AIS traffic data</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Study of maritime traffic</td>
<td>Comparison between AIS traffic data and MARTRAM simulation results</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Maritime traffic simulation program</td>
<td></td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Conclusions and recommendations</td>
<td></td>
</tr>
</tbody>
</table>
2 MARITIME SAFETY ASSESSMENT

2.1 Introduction

The problem definition given in the previous chapter is not new. Maritime traffic simulation programs were first developed and used for maritime risk assessments more than 30 years ago, and there has been awareness of the deficiencies of this method from the start. Much research has been carried out on various related topics since, an overview of which will be given in this chapter. This chapter will function as a framework for the rest of this thesis.

Paragraph 2.2 begins by giving general information about maritime transport. Paragraph 2.3 explains the present situation concerning maritime risk assessment methods. In paragraph 2.4 an overview is given of existing maritime traffic simulation programs. Paragraph 2.5 contains information about vessel safety domains. A number of previous studies into collision probabilities are described in paragraph 2.6 and this chapter ends with summarising conclusions in paragraph 2.7.

2.2 Maritime transport

At present approximately 90 per cent of global trade is transported by the international shipping industry. 27,635 billion ton-miles were transported over sea in 2004 and this number continues to increase as can be seen in Figure 2-1. This is due to the increasing efficiency of seaborne trade and the fact that the freight costs are remaining very low. An additional advantage of maritime transport is that it is one of the least environmentally damaging methods of transport. Transport by ship has lower CO\textsubscript{2} emissions per ton-km than both air freight transport and road transport by truck.

![Figure 2-1, World seaborne trade 1970-2005](www.marisec.org)

In January of 2006 the world fleet consisted of 47,681 seagoing merchant vessels. Figure 2-2 on the following page shows the distribution of the various ship types, general cargo ships being the most common. The average age of the world fleet of propelled sea-going merchant ships greater than 100GT is 22 years.
Up until the 1960’s, maritime transport was hardly regulated. But due to the continued increase in seaborne trade it became necessary to introduce traffic rules to improve the safety in maritime transport. In 1960 the first International Convention for the Safety of Life at Sea (SOLAS) was adopted. This convention included a set of Collision Regulations, aimed at organising maritime traffic and increasing safety. In 1972, the International Maritime Organisation (IMO) issued the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs), these are the maritime traffic rules as we still know them today. Later, in 1979, the International Association of Lighthouse Authorities (IALA) was formed to unify the world’s buoyage system [www.imo.org].

Besides regulations, new technological developments have also contributed to the management of the ever increasing maritime transport and the improvement of its safety. The first harbour control radar was installed on the Isle of Man in 1948. Since then, harbour control systems have developed into what is now known as Vessel Traffic Services (VTS). VTS actively monitors vessels in confined and busy waterways and provides navigational advice. The most recent technological development in maritime traffic management is the Automatic Identification System (AIS). In 2004 this system became compulsory for most sea-going vessels (vessels > 300 gross tonnage) as well as for all passenger vessels [www.navcen.uscg.gov]. More information about AIS can be found in Chapter 4.

Another form of transport that is closely related to maritime transport and which is also relevant for this study is inland waterway transport. In Europe alone, approximately 450 million tons of cargo is annually transported by inland waterway transport. Much of this cargo is destined for, or originates from one of the ports on the European coast. Inland waterway transport is a cheaper and environmentally friendlier alternative for road or rail transport. Inland waterway transport is presently dominated by dry bulk, of which 264.6 million tons was transported in 2001. But this is changing as the transport of containers and general cargo is rapidly increasing. In 2001 95.7 million tons of general cargo was transported and only 18 million tons of cargo in the form of containers. However, the transport of general cargo is predicted to increase by 25% between 2002 and 2010 and the transport of containers is expected to increase by almost 40% [http://ine.dad.be].

Many ports worldwide provide services for a combination of sea-going vessels and inland waterway vessels.
2.3 Maritime risk assessment methods

In quantitative safety analyses, the term Risk is defined as: Risk = probability * consequence. The general practice in conducting a risk assessment is to determine the risk for a number of alternatives, after which the practicable situation with the lowest risk is chosen. This lowest risk option is called the ALARP option, which is an abbreviation for As Low as Reasonably Practicable.

In maritime transport various risks can be identified such as grounding risk, fire risk and collision risk. This thesis will focus on the collision risk. Unfortunately in maritime transport it is not yet possible to quantify the risk of collision in restricted waters. It is difficult to quantify the consequences of a collision as these can consist of material damage to the ship, its surroundings and the environment, but also indirect damage such as loss of future income or even injuries and deaths. Moreover, the collision risk cannot be defined because the exact probability of a collision in restricted waters is not known. Much research into collision probability has been carried out but more is required to obtain answers to the remaining questions on this topic.

In absence of a quantitative risk assessment methodology for collisions, various qualitative risk assessment methods have been developed. The most common ones will now be described briefly.

In 2002 the International Maritime Organisation (IMO) introduced the Formal Safety Assessment (FSA). The IMO describes it as “a rational and systematic process for assessing the risks relating to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO’s options for reducing these risks.” This methodology consists of the following 5 steps:

1. Identification of hazards (a list of all relevant accident scenarios with potential causes and outcomes)
2. Risk analysis (evaluation of risk factors)
3. Risk control options (devising regulatory measures to control and reduce the identified risks)
4. Cost benefit assessment (determining cost effectiveness of each risk control option)
5. Recommendations for decision-making (information about the hazards, their associated risks and the cost effectiveness of alternative risk control options is provided)

A flowchart of the FSA methodology is given in Figure 2-3 on the following page.
However, the Committee V.1 Collision and Grounding of the International Ship and Offshore Structures Congress states that the Formal Safety Assessment methodology provided a basis in theory but that there is still a lack in uniformity in its applications [ISSC, 2006].

The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) attempted to solve this problem by developing a Risk Management Tool for Aids to Navigation and VTS Authorities in 2006. This tool consists of a Preliminary Qualitative Risk Assessment model called the Port and Waterway Safety Assessment Model (PAWSA), as well as a more detailed Quantitative Risk Assessment model called the IALA Waterway Risk Assessment Programme (IWRAP).

PAWSA was developed by the US Coast Guard in the 1990’s and was used to help evaluate the need for Vessel Traffic Management (VTM) and to plan future VTM projects. The PAWSA process consists of subjectively assessing the risk level of a waterway based on the expert opinion of various stakeholders such as vessel operators, pilots, port authorities and environmental interest organisations. It is based on the Port Risk Model that was designed by a National Dialogue Group on National Needs for Vessel Traffic Services (NDG) which includes a list of risk factors that affect port and waterway safety. These risk factors are indicated in Figure 2-4. The PAWSA process consists of five main steps which are shown in Figure 2-5 [OFFICE OF VESSEL TRAFFIC MANAGEMENT (G-MWV), 2005].

IWRAP is a risk analysis computer program in which sections of a waterway can be investigated using available traffic data and various meteorological and hydrological conditions. This program was developed by the Canadian Coast Guard. It is capable of calculating the minimum safe channel width for vessels taking into account aids to navigation as well as the effects of wind and current. These channel width calculations are based on the PIANC guidelines. The IWRAP model is also capable of approximating the collision probability between vessels. This approximation requires actual vessel track information to determine the vessel distribution in the channel. It then uses the encounter theory to estimate the collision probability. This process was briefly described in paragraph 2.1 and will be explained in more detail in paragraph 2.4 [http://site.ialathree.org].

As these tools have only recently been developed it cannot be said whether they have indeed improved the uniformity and quality of the FSA methodology.
Waterway Risk Model

<table>
<thead>
<tr>
<th>Vessel Conditions</th>
<th>Traffic Conditions</th>
<th>Navigational Conditions</th>
<th>Waterway Conditions</th>
<th>Immediate Consequences</th>
<th>Subsequent Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow Draft Vessel Quality</td>
<td>Volume of Small Craft Traffic</td>
<td>Water Movement</td>
<td>Dimensions</td>
<td>Petroleum Discharge</td>
<td>Environmental</td>
</tr>
<tr>
<td>Commercial Fishing Vessel Quality</td>
<td>Traffic Mix</td>
<td>Visibility Restrictions</td>
<td>Bottom Type</td>
<td>Hazardous Materials Release</td>
<td>Aquatic Resources</td>
</tr>
<tr>
<td>Small Craft Quality</td>
<td>Congestion</td>
<td>Obstructions</td>
<td>Configuration</td>
<td>Mobility</td>
<td>Economic</td>
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</tbody>
</table>

Figure 2-4, Risk factors affecting port and waterway safety
[Office of Vessel Traffic Management (G-MWV), 2005]

Another tool which is frequently used for qualitative maritime risk assessments is maritime traffic simulation programs. These programs can be used to carry out Steps 2 and 3 in the FSA methodology. A description of these programs will be given in the following paragraph.

2.4 Maritime simulation programs

Existing maritime simulation programs can be divided into two different categories. The first consists of computer programs that focus on the path of a single vessel. These programs are used to simulate the precise path taken by this vessel while taking into account hydrodynamic influences such as currents and waves. They can either work in Real Time or in Fast Time. The Real Time programs are often used in bridge simulators, in which a human operator actively takes part in the navigation, but they can also be used on a regular PC. Bridge simulators are used for research or training purposes. Fast Time programs are generally used on a PC. They use an autopilot that tries to follow a previously programmed
path as accurately as possible, given certain external influences such as currents, wind and waves. These Fast Time programs are able to simulate the manoeuvring behaviour of a single vessel in great detail. Together with the high speed at which they are able to carry out these simulations this makes these programs ideal for the preliminary design process of ports and waterways. However these programs are not yet capable of modelling multiple vessels simultaneously.

These programs are called Fast Time Manoeuvring Simulation Programs and an example of such a program is SHIPMA. SHIPMA was developed by WL Delft Hydraulics. Information about this program can be found in Appendix A-1.

The second type of maritime simulation programs can model multiple vessels. These so-called maritime traffic simulation programs are used to simulate the traffic flow along navigation channels. Like Fast Time Manoeuvring Simulation Programs, these programs are used in the design phase of ports and waterways. But maritime traffic simulation programs focus on the global channel layout rather than the precise channel dimensions. Maritime traffic simulation programs can be used to determine the capacity and safety of various port designs in present as well as in future traffic situations. These programs are only suitable to be used in areas where navigation channels are clearly present, such as in port areas and their approaches and also corridors at sea. These programs are less detailed than the first program type and they are not able to take any hydrodynamic influences or weather conditions into account. Neither are they capable of directly simulating human behaviour such as the navigational capabilities of the vessel’s captain. In such programs the vessels move along designated “lanes”, abiding by a number of traffic rules based on COLREGs. Each vessel type is assigned a safety domain, representing a virtual area around the vessel that must remain clear for safety purposes. For example, a small general cargo vessel will require a smaller safety domain than a large oil tanker. More information on vessel safety domains can be found in paragraph 2.5.

Whenever two vessels come within a certain distance to one another, this is called an encounter. The moment at which an encounter is registered can either be the moment that the safety domains of two vessels overlap or the moment when one vessel enters the safety domain of the other vessel, depending on the program. Such programs require the definition of safety domains for the various vessel types in the model, which are frequently expressed in terms of the ship length and ship width. The maritime traffic simulation programs count the number of encounters that occur in the modelled area during a simulation run. By modelling various alternative situations and comparing the number of encounters occurring in each, conclusions can be reached about the relative safety of the different channel designs and port layouts.

These conclusions are only valid if identical vessel safety domains have been used in each alternative situation as the number of encounters calculated depends on the size of these safety domains. However, a universal relationship between the size of the safety domain of a vessel and the probability of a collision is yet unknown. This method of encounters cannot be used on its own to predict the maritime safety in terms of collision probability. In order to do so, incident statistics must be available for the existing situation that is modelled on which the various alternatives are based. This existing situation can then be used as a base-case for the model against which the alternative designs can be evaluated. The incident statistics can be used to calibrate the model by finding an empirical relationship between the calculated number of encounters and the number of collisions that have occurred in reality. However such a relationship can only be found if a large volume of incident data is available, which is often not the case. For new ports or waterways, such data is not available at all. As a result it is impractical to quantify the risk of a collision using the output of the maritime traffic simulation programs. Their results should only be used as a qualitative indication of the relative safety of the various alternatives.
The quality of these maritime traffic simulation programs varies, as some are more realistic than others. Existing programs are not able to accurately model the precise vessel behaviour in close proximity to other vessels, because this largely depends on the human behaviour of a captain. However, in some programs the vessels are capable of some form of automated encounter avoidance behaviour based on COLREGs.

This human behaviour is difficult to model correctly for the following reason. Three different types of human behaviour can be identified: skill-based behaviour, rule-based behaviour and knowledge-based behaviour. Skill-based behaviour is based on stored patterns of behaviour which a person is able to carry out with little conscious effort. Rule-based behaviour is based on prescriptive rules or procedures. And finally, knowledge-based behaviour is based on using available knowledge in new situations, which requires cognitive processes such as problem solving and planning [Seignette, 2002]. The behaviour of a captain while navigating his vessel is considered to be knowledge-based behaviour and available computer systems are not able to simulate such cognitive processes as required.

At the moment attempts are being made to approximate human behaviour in maritime traffic simulation programs using a technique called fuzzy logic modelling. Amongst others, Papenhuijzen, 1994 and Mou, 2006 have carried out research into this topic. Fuzzy logic modelling is based on the Fuzzy Set Theory which was introduced by Dr. L. Zadeh in 1965. In traditional mathematics an object can either be a full member of a given set or not a member at all. The fuzzy set theory enables degrees of membership [Papenhuijzen, 1994]. In fuzzy logic modelling, large amounts of input data are processed according to various ‘If-Then’ rules, similar to those that occur in the human brain. Weighting and averaging of the resulting outputs then leads to a single output signal. This ability of taking in and evaluating large amounts of data, leading to a decision on how to act is what makes fuzzy logic modelling so suitable for modelling human behaviour [www.fuzzy-logic.com].

A combination between the Fast Time / Real Time Manoeuvring Simulation Programs and the maritime traffic simulation programs described above has still to be developed. As yet, such a combination would not be sensible because of the difference in their levels of detail. It would be of no use to model the precise reaction of a vessel to a current if its reaction to a passing vessel is inaccurate.

This thesis will continue to focus on maritime traffic simulation programs. Fast Time and Real Time Manoeuvring Simulation Programs will not be considered further. Examples of maritime traffic simulation programs are DyMITRI and MARTRAM.

General information about the MARTRAM program can be found in Appendix A-2 and Chapter 5 contains a more detailed description of how the program works and how it should be used.

2.5 Vessel safety domains

Nowadays the vessel safety domain is a very common concept in maritime transport. It is used for various purposes such as traffic lane design and capacity studies, for risk assessments and as encounter criterion in maritime traffic simulation programs. Even so, there is no universal definition for the concept of vessel safety domains. Research has been done on this concept since the end of the 1960’s and various researchers have come up with their own theories as well as different names for this concept. This lack of uniformity is possibly the reason that vessel safety domains are not used in maritime traffic management or to set up maritime traffic guidelines. Throughout this report the name vessel safety domain will be used.
In this thesis, the focus will be on the vessel safety domain’s function as encounter criterion in maritime traffic simulation programs. This paragraph gives an overview of the most frequently used definitions of vessel safety domains in order to indicate the diversity of this expression and the need to continue research on this topic. This diversity is illustrated in Figure 2-6, in which various types of vessel safety domains are drawn around a vessel of approximately 100 metres in length. In this figure the vessel is indicated in black.

Figure 2-6, Vessel safety domains for a vessel with length of approx. 100 metres
[TEN HOVE et al., 2005]

Together with S. Toyoda, Y. Fujii started doing research on vessel safety domains in Japanese waters in 1967. He measured the speed and length of a great number of ships at various locations, as well as the minimum distance between these ships. Fujii proposed the following definition of an effective domain which he also called the bumper zone: ‘a two-dimensional area surrounding a ship which other ships must avoid. It may be considered as the ‘area of evasion’’ [TOYODA and FUJII, 1971]. This safety domain has the shape of an ellipse and is indicated by the red dotted line in Figure 2-6.
In 1975, after observing various traffic situations as well as carrying out collision avoidance simulations, Goodwin proposed the following definition of the ship domain: ‘the effective area around a ship which a navigator would like to keep free with respect to other ships and stationary objects’ [GOODWIN, 1975]. This definition is illustrated in Figure 2-7, which shows the relative tracks of other ships around a central ship resulting in a free area. TEN HOVE et al., 2005 as well as ZHU et al., 2001 have commented on the contradiction in this definition, as the word ‘effective’ implies an objective domain and ‘would like to keep free’ implies a subjective domain. As Goodwin based her research on observations of ships and their behaviour, her model can be considered to be an objective one.

![Figure 2-7, Domain boundary suggested by the relative tracks of other ships during a crossing of the English Channel [GOODWIN, 1975]](image)

GOODWIN, 1975 also investigated the dimensions of this ship domain. A radar survey was held on board a vessel during a total of 48 hours near Harwich in the United Kingdom. During this time, every 3 minutes a photograph was taken of the radar display. This radar data was then analysed for every one ship on the radar display by plotting the positions of all other ships in her vicinity at any given point in time. These distributions for various times were then superimposed to show the total distribution of ships around this central ship. If the ship had not been present, the distribution of all other ships in the area would be a straight line of which the slope depends on the overall density of ships in the area and the size of this area. This is indicated by the black line in Figure 2-8. However, in the presence of this ship, other ships that would have been close to her will have displaced away from her. This is indicated by the red dotted line in Figure 2-8. Goodwin defined the size of the domain by the point $X_A$ in this figure. For a distance smaller than $X_A$ fewer ships are present than if a domain had not been present. These ships have displaced to a distance greater than $X_A$ away from the central ship. From this figure it can be concluded that the area where the Goodwin survey was carried out was in fact not entirely “open” water. If this had been the case, a maximum would not have been visible. This can be explained as follows: if all vessels would have been entirely free to navigate, they would do so in such a manner that no concentration of vessels would occur in any location.

GOODWIN, 1975 continued by claiming that the shape and size of the ship domain depends on psychological factors such as length of sea experience of the navigator, physical factors of the specific ship such as dimensions and speed, and also on physical factors of the area such as traffic density and weather conditions. She discerned three sectors around the vessel so that each sector has a different vessel safety domain radius, as can be seen in Figure 2-6. Each of these radii was determined using the method described above.
Figure 2-8 as well as the dimensions of the vessel safety domains derived from it are only valid for the specific area in which the traffic survey was carried out.

Fujii used a similar approach to the dimensioning of vessel safety domains as Goodwin, except Fujii based the dimensions of the domain on the distance from the central vessel at which the density of other vessels reaches a local maximum [TEN HOVE et al., 2005]. This point is indicated by $X_B$ in Figure 2-8. GOODWIN, 1975 remarked that as this is a distance to which a large number of ships have been displaced, this is an over conservative estimate of the domain size.

COLDWELL, 1983 proposed that the difference in definitions proposed by Fujii and Goodwin was caused by the difference in their respective survey areas. The study carried out by Fujii was focused on two areas where the vessel mix was not very large and where navigation channels were present. Goodwin on the other hand carried out work in relatively more open waters with a larger mix of vessel types and dimensions. Coldwell also stated that the choice between using the Fujii approach or the Goodwin approach will depend on the purpose of the analysis. He explained that Fujii is most suited to investigate channel capacity and safe navigation, whereas Goodwin is most suited if there is an interest in a critical danger factor.

Most theories about vessel safety domains were based on situations at open sea. Only COLDWELL, 1983 investigated vessel safety domains for restricted waterways. His research was carried out on the Humber, which is an estuary on the East coast of the United Kingdom leading to the port of Hull. The average width of the Humber is approximately 0.4 to 0.5 nautical miles (approximately 740 to 925 metres). He proposed the following definition of the vessel safety domain: ‘the effective area around a vessel which a typical navigator actually keeps free with respect to other vessels’. Coldwell studied 64 hours of radar data. For each vessel in the survey area, the relative bearings and distances of all other vessels were measured at 3-minute time intervals. In this way a distribution of ships around a central vessel was plotted. Coldwell then defined the dimensions of the vessel safety domain as the location of maximum density of other vessels around this central vessel. The definition of Coldwell’s domain for restricted waters is indicated by $X_{FR}$ in Figure 2-9. Coldwell used an approach similar to that of Fujii, as both took the maximum of the vessel density around the central ship to be the location of the vessel safety domain. Figure 2-9 demonstrates that the maximum in vessel density is much more pronounced for restricted waters than it is for relatively open waters. Again, this figure is only suitable for the specific traffic situation from which it was derived.
DAVIS et al., 1980 introduced a so-called arena in addition to the vessel safety domain. This arena consists of a circle with the ship off-centre. It indicates the area around a ship where a navigator feels threatened by another ship and decides what action, if any, is needed to keep his own domain clear of other ships. The arena is therefore always larger than the vessel safety domain. In the previous paragraph it was mentioned that in some maritime traffic simulation programs the vessels are capable of some form of automated encounter avoidance behaviour based on COLREGs. To facilitate this, a certain distance must be defined in the program where a vessel decides to either maintain course or to carry out an encounter avoiding manoeuvre according to the COLREGS. This distance is indicated by the arena around a vessel.

The dimensions of the arena defined by DAVIS et al., 1980 can be seen in Figure 2-6. The concept was developed for deep-sea situations with no restrictions, therefore the proposed dimensions will not be suitable for situations of restricted water however the concept can be applied.

ZHOU et al., 2001 were the first to make a distinction between the definitions of subjective and objective ship domains: ‘The subjective domain is the waters that a navigator really “wants” to be kept safe, usually used for risk assessment by the navigator, while the objective domain is the facts that a navigator “has to” accept.’ From a series of consultations with veteran navigators it was found that a ship’s domain is mainly affected by the local visibility, the manoeuvrability of the ship and the bearing of the Closest Point of Approach between vessels.

NAGASAWA et al., 1988 supported the definition of vessel safety domain proposed by Goodwin, however they added to this that the boundaries of this domain can be influenced by various external factors. They proposed an elliptical domain of which the dimensions depend on the vessel speed. The reason for this being that during simulator tests it was found that the time to closest point of approach (TCPA) was more closely related to the moment at which an encounter avoidance manoeuvre was started than the closest point of approach (DCPA) was. The position of the ship within this domain could then vary depending on the traffic situation.

In summary, Figure 2-6 clearly indicates that so far no consensus has been reached concerning the shape and dimensions of the vessel safety domain. Most of these differences in dimensions are caused by the different definitions used, however differences can also be caused by the variations in traffic between the areas in which each study was carried out.
It is also necessary to comment on the suitability of these various dimensions in situations of restricted waters. There is an important difference in navigational behaviour between situations of open water and restricted water. In restricted water, vessels generally navigate at a lower speed than in open water and vessels are required to navigate in closer proximity than would be considered safe in open waters. But the captains know this and therefore anticipate and tolerate other vessels in close proximity to their own vessel. It is important that this is reflected in the dimensions of the safety domains used so that an encounter actually represents an undesirable and possibly hazardous situation. It is important that more research is carried out into the dimensions of vessel safety domains specifically for restricted waterways so that these can be used to define encounters in maritime traffic simulation models.

Finally, it must be remarked that the vessel safety domain is a tool used to define encounters, and encounters are merely a tool to qualitatively determine collision probability. Other methods to qualitatively determine the collision probability have been developed but these are not widely used. Two examples which will be described briefly are the penalty function method developed by R. Papenhuijzen and the method of Stress Ranking which was developed by K. Inoue.

The penalty function method was developed for use in a manoeuvring simulation program. This method consists of a regular evaluation of the optimum future position within the waterway from the perspective of the vessel. Each location along the waterway is assigned penalties, depending on the distance to the bank, the water depth, the distance to other vessels or obstacles, and more. The vessel then follows the route with the lowest total penalty. The advantage of this method is that it recognises that the acceptable distance to hazardous objects can vary depending on the situation instead of being fixed such as in the method of vessel safety domains. But the disadvantage of the penalty function method is that it requires the definition of a penalty system for each waterway it is applied to. The definition of such a penalty system will be equally complex as defining a vessel safety domain [TEN HOVE et al., 2005].

The Stress Ranking method consists of determining the level of stress around a vessel. This level of stress reflects topographical conditions such as land and buoys, traffic conditions such as the density of other ships and external disturbances such as winds and currents. The stress values of each of these conditions are determined on the basis of the time to collision (TTC) with any obstacles or other vessels and they represent the available sea space around the vessel. This method requires a stress value to be determined for every degree between -90° to +90° around the present course of the vessel. These are then summated to determine the total stress level of the specific situation. The stress values range between 0 and 6, 0 indicating an extremely safe situation and 6 indicating an extremely dangerous situation. These values were calibrated by carrying out simulator research and questionnaires [INOUE, 2000]. Stress Ranking is therefore a subjective method with the same disadvantage as the penalty function method: defining the stress levels for each possible scenario is a very complex and time consuming task.

2.6 Studies into collision probability

As mentioned previously, maritime safety can be expressed in terms of collision probability. This collision probability between vessels depends on many different factors such as:
- maritime traffic situation (channel layout, traffic intensity, level of VTS management)
- weather conditions (wind, currents, visibility)
- vessel characteristics (vessel type, vessel age, manoeuvrability, available bridge equipment)
human factors (experience and capability of the captain and his crew, working conditions)

However the extent to which these factors influence the collision probability has not been quantitatively defined.

Different approaches are possible towards learning more about collision probability. A frequently used method is to investigate collision statistics in certain areas. If sufficient amounts of sufficiently detailed statistics are available, conclusions can be made regarding the situations in which collisions are likely to occur as well as the various factors influencing the collision probability. The disadvantages of this method are that such collision statistics are only available for a very limited number of areas. Also, the conclusions based on the statistical analysis of the data are only valid for the specific locations that were investigated. Care must also be taken if these conclusions are applied to future situations as the situations will change over time. For example, the traffic composition will change, available navigational equipment will improve and vessels are assumed to become larger and faster (INTERNATIONAL SHIP AND OFFSHORE STRUCTURES CONGRESS, 2006).

An attempt was made by Psaraftis et al., 1998 to identify factors that make a statistically significant difference on maritime transport risk. This maritime transport risk concerns maritime accidents ranging from hull problems to collisions. Based on the Lloyds List Casualty reports and casualty files from the Greek Ministry of Merchant Marine a correlation was established between the ship type and the probability of an accident. The following numbers are based on the composition of the world fleet at the time of this investigation.

It was found that passenger vessels were most likely to be involved in an accident (96 ships out of a thousand passenger ships were involved in an accident). Tanker vessels have the lowest probability of being involved in an accident (71 ships out of a thousand tanker vessels were involved in an accident). The ship age was also found to be of influence. According to this study, ships between the age of 15 and 19 have the highest accident probability. And finally, the ship flag and country of ownership were also found to influence the accident probability.

However Soma, 2004 says that 'the ship age does not describe the vessels’ intrinsic technically accident risk’. In his research he found that the higher accident risk associated with older vessels is actually caused by the policy and capability of the ships managing companies. He argues that small and relatively inexperienced management companies usually own older vessels. These vessels are sold by the larger companies as these can afford to regularly replace older vessels by newer, more advanced and safer vessels. This train of thought can even be continued to include the staff on board the vessel. Smaller companies generally have a lower budget and possibly work with lower standards, lower pay and therefore lower quality of captains. This will in turn lead to a higher likelihood of human errors and further increases to the collision probability. However this is merely an assumption and more research is required to confirm whether it is true. It does indicate that there are relationships between various factors (for example between vessel characteristics and human factors) and these relationships also need to be investigated.

Apart from investigating the various factors that might influence the collision probability, some studies focus on the assumed collision cause. The word ‘assumed’ is very important, as defining a single collision cause is very complicated. According to Soma, 2004 ‘It is common to describe individual causal events as insufficient but necessary parts of unnecessary but sufficient conditions’ that result in losses. Hence, an event is a cause of an accident if the elimination of the event would have prevented the accident from occurring.’ But identifying such causal events after a collision has taken place is very difficult.
In Psaraftis et al., 2000 an analysis of marine accident records collected by the Greek Ministry of Merchant Marine was carried out. 75 accident records were investigated and the majority of accidents were found to have had more than one cause. One accident was even assigned 14 different causes.

From this research it appeared that the most frequently occurring accident cause was ‘Existing routines for safety control known, but not followed’ in 8.2% of all cases, followed by ‘Insufficient real competence (practice from occupation, waters, with equipment or suchlike)’ in 7.9% of all cases. These are both human errors. In fact it was found that the majority of all accidents were caused by one or more human errors, rather than by external situations such as extreme weather or mechanical errors like machinery failure. And Psaraftis argues that in the cases that were found to be caused by external factors, it was in fact the combination of the external factor and a human error that lead to the accident. ‘If the Master took the proper measures (such as reduce speed, change course, go to a safe place, send distress signal, etc), the accident might not have occurred, even though the weather was bad.’ This dominance of human error has previously been demonstrated in several independent studies. Soma, 2004 states that at least 80 to 90 percent of maritime accidents are caused by human errors.

Another method to gain insight into collision probability is to focus on certain individual elements that influence this probability. Often bridge simulations are carried out to investigate the influence of elements such as channel layout, visibility and vessel manoeuvrability. If these simulations are correctly set up and various situations are tested the conclusions obtained from this type of research are applicable to various maritime situations and not bound to a certain location as the previous method is. Another advantage of bridge simulations is that human behaviour in various situations can be considered. Although human errors are the most important cause of maritime accidents, still not much is known about human behaviour in navigation. One aspect of human behaviour that is especially of interest for maritime navigation is the decision-making process. Many studies have been carried out to learn about the distances at which navigational decisions are made, for example when an encounter avoiding manoeuvre is started.

In Kobayashi, 2006 mariner’s behaviour was investigated during simulations of several manoeuvring situations at open sea. The following points of importance for the mariner’s encounter avoidance behaviour were identified and the results for this study will now be highlighted according to these points:

- First detection of target vessel
- First recognition of target vessel as the dangerous vessel
- The situation at starting action for avoiding collision
- The situation at the closest point of approach

The influences of the following factors were investigated in conditions of good visibility: own ship length, own ship speed, crossing angle, target ship speed and navigational water area. Figure 2-10 indicates the crossing angles as they were defined in this study.

No relationship was found between the distance at first detection of target vessel and crossing angle and relative speed. All detections took place at distances of approximately 8 miles. It was found that for increasing crossing angles ranging from 45 to 135 degrees, the distance where the mariner recognised the target vessel as dangerous increased from 5 to 6 miles. Also, when the crossing angle became larger within this range from 45 to 135 degrees, the action to avoid collision was started earlier (at a relative distance of 5 miles as opposed to 3 miles).
Finally, the distance to target at CPA, also called DCPA, was corrected for the length of the own vessel after which it was found that the DCPA decreased slightly as the crossing angle increased from 45 to 135 degrees.

It must be remarked that the variation in mariner’s behaviour in these simulations was very large, especially the variation of the detection points.

![Figure 2-10, Definition of crossing angles]

[KOBEYASHI, 2006]

Another example of such a simulator study is one described in NISHIMURA 2006, in which the effects of restricted visibility were investigated. It was found that under restricted visibility, the radar watch area was decreased and that mariners were delayed in timely understanding a target vessel’s behaviour. This was indicated by the fact that in many of the collision cases that occurred, the target vessel had been detected on radar at an early stage.

Each of these studies clarifies a particular aspect of human behaviour in maritime traffic. Eventually, all such results and conclusions must be combined and used in the development of a method to model this human behaviour. This will be a large step forward towards finding a link between encounter probability and collision probability.

Finally, valuable information concerning collision probability can be obtained by interviewing experienced captains. Their insights into maritime situations and circumstances can also lead to a greater insight into the factors that have a significant effect on the collision probability.

For this thesis, an interview was set up in which 5 captains of RoRo vessels (of length 147 metres) took part. These captains sailed a regular service between Dagenham (United Kingdom) and Zeebrugge (Belgium) and all possessed Pilotage Exemption Certificates for the Port of London area. The number of years of experience of these captains ranged from 3 months to 9 years. They were each asked to rank various factors that are thought to influence the collision probability in restricted waterways. These factors can be seen in Table 2-1, along with the scores between 1 and 5 that were assigned by the captains. A score of 1 means the influence on the collision probability is negligible and a score of 5 indicates that the factor is thought to have a significant influence on the collision probability. In this table the influences have been arranged in three categories, being sailing characteristics of the vessels involved, external factors relating to the traffic situation and the weather situation.
and finally the situation on the bridge, which concerns the people involved in the navigation of the vessel. It is important to remark that the influences on collision probability can in fact not be grouped in such a straightforward manner as was done in this table. It may be assumed that relationships exist between the various influences which complicate this categorisation.

<table>
<thead>
<tr>
<th>Possible influences on collision probability</th>
<th>Captain 1</th>
<th>Cpt. 2</th>
<th>Cpt. 3</th>
<th>Cpt. 4</th>
<th>Cpt. 5</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sailing characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vessel type and dimensions of vessels involved</td>
<td>1</td>
<td>3 - 4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>16.5</td>
</tr>
<tr>
<td>Speed of vessels involved</td>
<td>1</td>
<td>3 - 4</td>
<td>5</td>
<td>4</td>
<td>4 - 5</td>
<td>18.0</td>
</tr>
<tr>
<td>External factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic intensity</td>
<td>High</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>20.0</td>
</tr>
<tr>
<td>Channel layout</td>
<td>Channel straight or bendy</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Shallow areas</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>15.0</td>
</tr>
<tr>
<td>Permanent objects</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>15.0</td>
</tr>
<tr>
<td>Visibility</td>
<td>Night</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>12.0</td>
</tr>
<tr>
<td>Light fog</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>18.0</td>
</tr>
<tr>
<td>Heavy fog (visibility&lt;1000m)</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>23.0</td>
</tr>
<tr>
<td>Wind</td>
<td>Heavy cross winds</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Heavy winds from the front</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>9.0</td>
</tr>
<tr>
<td>Heavy winds from behind</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>10.0</td>
</tr>
<tr>
<td>Currents</td>
<td>Strong in cross direction</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Strong from the front</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>8.0</td>
</tr>
<tr>
<td>Strong from behind</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>3 - 4</td>
<td>14.5</td>
</tr>
<tr>
<td>Sea state</td>
<td>Heavy seas</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>Type of encounter</td>
<td>Meeting</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>12.0</td>
</tr>
<tr>
<td>Overtaking</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>15.0</td>
</tr>
<tr>
<td>Crossing</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>19.0</td>
</tr>
<tr>
<td>Situation on bridge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of people present</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>11.0</td>
</tr>
<tr>
<td>People rested</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>12.0</td>
</tr>
<tr>
<td>People experienced</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>21.0</td>
</tr>
<tr>
<td>Pilot present</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Table 2-1, Ranking of influences on collision probability based on interviews

The results presented in this table illustrate the subjectivity of the answers as there is a significant variation in the scores provided by each of the captains. These differences possibly indicate previous personal experiences with dangerous situations and they highlight the subjectivity of such an investigation. However, it was possible to identify five factors that were considered to have the greatest influence on the collision probability. The factors with the highest total ranking were: Heavy fog (score 23), People experienced (score 21), High traffic intensity (score 20), Crossing encounter (score 19) and Strong currents in cross direction (score 19).
2.7 Chapter conclusions

This chapter demonstrates the great range of different topics related to maritime safety assessment and the large amount of research done. Below is a list of the most relevant findings for the rest of this thesis.

- Maritime transport is an indispensable mode of transport and its continued increase demands a more sophisticated form of risk assessment than is presently available.
- Fast time manoeuvring simulation programs are useful in determining likely paths of individual vessels but do not model multi-vessel interaction.
- Maritime traffic simulation programs are a very useful tool in assessing the relative safety of different alternatives but they do not model at individual vessel level. The effect of various influences such as the element of human behaviour is not included although this is essential in qualitative maritime safety assessment.
- Basing these maritime traffic simulation programs on the theory of vessel safety domains appears to be logical and feasible however it is necessary to look into the specific situation of restricted waterways and to adjust the vessel safety domain sizes to suit these circumstances.
- Bridge simulation is a valuable tool in understanding vessel responses to given conditions but does not model multi-vessel interaction.
- Analysis of incident data can provide in useful insight but the data is generally specific to certain locations and conditions. There is often insufficient data available to allow meaningful quantitative analysis for specific locations.
- Collision probability is a complex topic which depends on a large number of factors. Besides investigating each of these topics separately it is important to recognise the relationships between them and to take these influences into account.
3 MARITIME INCIDENT DATA

3.1 Introduction

Various organisations worldwide keep records of maritime incidents. These organisations each have their own methods for doing so. The geographical area of coverage, the quality of information recorded, and the manner of distributing this incident data varies greatly. Much can be learned from maritime incident data. This knowledge can be used to aid in assessing and improving maritime safety. For this study, maritime incident data was collected and sorted. This chapter contains an analysis of the information related to vessel-vessel collisions with both vessels underway. The aim of this analysis is to provide an answer to the first research question posed in Chapter 1:

Which factors have the greatest influence on the probability of a collision between vessels underway in restricted waters?

First an overview will be given of available sources of maritime incident information in which the data provided by each source will be briefly discussed. Paragraph 3.3 continues with a further analysis of data from a selection of these sources. Finally, the conclusions of this analysis are presented in paragraph 3.4.

3.2 Data sources

For this study, incident data was obtained from the following sources:

- The Global Integrated Shipping Information System (GISIS), property of the International Maritime Organization (IMO)
- The database of the Marine Accident Information Branch (MAIB)
- The PLACID database, property of the Port of London Authority
- The SOS database, property of the Dutch Transport Research Centre AVV
- The Marine Casualty and Pollution Database, property of the United States of America’s Bureau of Transportation Statistics

These sources and the data they provide will be briefly described below.

GISIS

During an international conference in Geneva in 1948 a decision was made to establish an international body to promote maritime safety more effectively. Ten years later the Inter-Governmental Maritime Consultative Organization (IMCO) came into force. In 1982 the organisation’s name was changed to International Maritime Organization (IMO). Now it is the largest maritime organisation worldwide. The IMO’s main task has been to develop and maintain a regulatory framework for shipping today. This framework addresses topics such as environment, legal matters, technical-cooperation, efficiency and safety. Related to safety, the IMO records maritime incidents in its Global Integrated Shipping Information System (GISIS). This system consists of individual reports for a great variety of incident types involving merchant vessels occurring worldwide, such as groundings, fires on board and collisions. The quality of these individual reports varies. A number of records include full reports with detailed descriptions and evaluations of the incidents, while others do no more than mention that an incident has occurred.
MAIB

The Marine Accident Information Branch (MAIB) is a department within the British Department for Transport. The MAIB investigates marine accidents worldwide in which UK vessels are involved as well as all marine accidents involving vessels occurring in UK territorial waters. Both accidents involving merchant vessels as those involving non-merchant vessels are considered. The MAIB issues individual reports on these accidents and produces an annual statistical summary. The quality of the individual reports varies.

PLACID

The Port of London Authority keeps records of various types of incidents occurring in the Port of London area and its approach channels. All vessel types are considered. These individual incident reports are kept in the Port of London Authority Computerised Accident Database (PLACID).

A distinction has been made between Navigational Occurrences and Safety Incidents. Navigational Occurrences are divided into various categories, ranging from erroneous navigation and incidents related to berthing or manoeuvring to the disregarding of port directions. Navigational Occurrences mostly do not have any serious consequences and result only in some form of warning or intervention by the Port Control Centre. Safety Incidents on the other hand usually do involve some form of damage or injury. Examples of Safety Incidents are collision, grounding, fire/explosion and near misses. The reports are not very detailed. They contain basic information about the vessels involved and sometimes also a brief description of the incident.

SOS

The SOS database is kept by the Dutch Transport Research Centre, which is part of the Ministry of Transport, Public Works and Water Management. It is a statistical database in which records are kept of navigational incidents occurring on Dutch territorial waters. It is used to monitor the safety on these waters. A navigational incident can be any occurrence ranging from a household incident on board a vessel to a collision between two vessels. All vessel types are considered.

Marine Casualty and Pollution Database

The Marine Casualty and Pollution Database is maintained by the United States of America’s Bureau of Transportation Statistics. The database provides detailed statistical information about all marine casualty and pollution incidents investigated by the U.S. Coast Guard Marine Safety Officer.

An overview of these incident data sources is given in Table 3-1.
### 3.3 Data analysis

In order to find an answer to the first research question defined in this thesis, many collision cases in restricted waters need to be considered. Of the various sources of information mentioned above, the sources containing statistical data are most suitable to do so. Although the MAIB’s Annual Reports also consist of statistics, these will not be used in this analysis because the locations of the incidents have not been specified and the distinction between open sea and restricted waterways cannot be made. Also, the MAIB statistics have already been grouped, therefore it is not possible to rearrange them to suit the aims of the analysis that is carried out in this chapter. The Marine Casualty and Pollution Database is also a statistical database, containing valuable information. But it is very large and the data can only be viewed in sections via the Internet. This is a very inefficient and time-consuming process therefore this database will not be used in this report. This leaves the PLACID Database and the SOS Database as the only readily useful sources of statistical information. The rest of this chapter consists of the analysis of data from these two sources.

Many factors influence the probability of a collision but these cannot all be investigated in this study. The content and quality of the available databases determines which factors can be investigated. These are the following, with the respective data sources given in brackets:

- Vessel type (PLACID, SOS)
- Pilotage situation (PLACID)
- Weather situation (SOS)
- Assumed incident cause (PLACID, SOS)
- Location of incident (PLACID)

Relevant factors which have not been investigated in this study due to lack of data include:

- vessel age and vessel flag
- vessel manoeuvring characteristics
- available navigational equipment on board
- level of VTS support given to vessels (traffic management)
- channel layout and quality of channel marking
3.3.1 PLACID analysis

For this research the PLACID reports of the years 1996 to 2006 have been used. A report was made for every known incident occurring in the Port of London area and its approach channels. As mentioned previously, in this database a distinction is made between Navigational Occurrences and Safety Incidents. The Navigational Occurrences will not be taken into consideration as they consist of minor incidents which are not relevant for finding the factors of influence on the probability of a collision.

The Safety Incidents are divided into 8 categories, being: contact (with a fixed object), collision, grounding, loss of hull integrity, swamping, pollution, fire/explosion and near miss. Between 1996 and 2006 only 3 collisions occurred. This is insufficient data to base any conclusions on, therefore the 24 near misses that occurred during this period will also be considered. As the name suggests, near miss situations are hazardous situations in which a collision could have occurred if avoiding action had not been taken. This implies that a number of factors causing a possible collision were present. Appendix D-1 contains an excerpt from the Navigational Safety Management System (SMS) manual [PORT OF LONDON AUTHORITY, 2003] in which the definition of a near miss is given.

The other incident categories included in the PLACID database (contact, grounding, loss of hull integrity, swamping, pollution and fire/explosion) will not be considered in this analysis as they do not provide any insight into collision probability. As this analysis is based on a total of only 27 incidents, the conclusions reached must be handled with care. The results will be presented below, and have been divided into the sections: Vessel type and pilotage situation, Assumed incident cause and Incident location.

Vessel type and pilotage situation

The PLACID reports contain three possible pilotage situations, being PEC vessels, piloted vessels or self takers. PEC stands for Pilot Exemption Certificate holders, indicating that the captains of these vessels have passed pilotage exams for certain areas they frequently visit and they are not required to take a pilot on board in these areas. The self takers are usually smaller vessels that do not require pilotage.

The results showing vessel types and pilotage situations for the collisions are given in the left five columns of Table 3-2 below. The vessel types and pilotage situations for the near misses are given in the right five columns of this table.
Table 3-2, Vessel types involved in incidents and their pilotage situation (PLACID)

<table>
<thead>
<tr>
<th>Vessel types</th>
<th>Collision</th>
<th>Near miss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pilot</td>
<td>PEC</td>
</tr>
<tr>
<td>Bulk carrier</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Container vessel</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>General cargo</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Reefer vessel</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>RoRo vessel</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tanker</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Barge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fishing vessel</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Yacht</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Dredger</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Workboat</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Tug</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Specialised service vessel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unknown vessel type</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

From this table it can be seen that a total of 50 vessels were involved in the 24 near miss situations considered. This is due to the fact that three vessels were involved in two of the near miss situations. Figures 3-1 to 3-7 highlight various data from this table.

From Figures 3-1 and 3-2 it can be seen that fishing vessels are most often involved in collisions, while general cargo vessels are most often involved in near miss situations. Container vessels and RoRo vessels are also involved in near miss situations more frequently than other vessel types.

Figure 3-1, Vessel types involved in collision (PLACID)

Figure 3-2, Vessel types involved in near misses (PLACID)
Before commenting on the influence of vessel type on the probability of becoming involved in a near miss situation, this data needs to be compared to the traffic data in the Port of London area. For a 5 month period from 28-07-2004 to 14-12-2004 the number of transits through the Port of London approaches was counted. This can be seen in the first three columns of Table 3-3. For this comparison it was assumed that the traffic data is representative for the period between 1996 and 2006 over which the PLACID data was collected. In reality, changes in the traffic situation will have occurred over these ten years, such as changes in vessel types passing through the area, changes in the layout of the area itself and changes in the vessel traffic management.

The last two columns of the table show the number of near misses that occurred in the Port of London area. The data in Table 3-3 is also presented in Figure 3-3.

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Number of voyages</th>
<th>Percentage of voyages</th>
<th>Number of near misses</th>
<th>Percentage of near misses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk carrier</td>
<td>301</td>
<td>2.9%</td>
<td>5</td>
<td>13.2%</td>
</tr>
<tr>
<td>Container vessel</td>
<td>918</td>
<td>8.7%</td>
<td>8</td>
<td>21.1%</td>
</tr>
<tr>
<td>Dredger</td>
<td>1038</td>
<td>9.9%</td>
<td>11</td>
<td>28.9%</td>
</tr>
<tr>
<td>General cargo</td>
<td>3133</td>
<td>29.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquefied gas</td>
<td>210</td>
<td>2.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naval</td>
<td>25</td>
<td>0.2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pallet carrier</td>
<td>37</td>
<td>0.4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger ship &amp; ferry</td>
<td>53</td>
<td>0.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reefer</td>
<td>182</td>
<td>1.7%</td>
<td>2</td>
<td>5.3%</td>
</tr>
<tr>
<td>Research</td>
<td>6</td>
<td>0.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RoRo</td>
<td>3151</td>
<td>29.9%</td>
<td>8</td>
<td>21.1%</td>
</tr>
<tr>
<td>Specialised cargo</td>
<td>52</td>
<td>0.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specialised service vessel</td>
<td>37</td>
<td>0.4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanker</td>
<td>1337</td>
<td>12.7%</td>
<td>4</td>
<td>10.5%</td>
</tr>
<tr>
<td>Tug</td>
<td>52</td>
<td>0.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10532</td>
<td>100.0%</td>
<td>38</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Table 3-3, Traffic data for the Port of London, 28-07-2004 to 14-12-2004
Table 3-3 and Figure 3-3 show that General cargo vessels and RoRo vessels pass through the Port of London area most frequently. Bulk carriers and Container vessels appear to call at the Port of London less frequently. It can be seen that the percentage of near misses in which the vessel types Bulk carriers, Container vessels and Reefers are involved is larger than the percentage of voyages they represent. This indicates that these vessel types are more likely to be involved in a near miss than other vessel types. Bulk carriers appear to be most likely to be involved in a near miss situation.

Although RoRo vessels frequently pass through the Port of London area, they are involved in a relatively smaller percentage of near misses. Together with dredgers, RoRo vessels appear to have the lowest likelihood of involvement in a near miss situation. A possible explanation for this low number of RoRo vessels being involved in near misses is that the majority of RoRo vessels in the Port of London area are PEC vessels and call at the Port of London regularly. These Pilotage Exemption Certificate holding captains are familiar with the area and also with each other, so they will be comfortable navigating at smaller distances to one another without considering it to be a hazardous near miss situation.

The data concerning the pilotage situations of the vessels involved in collisions and near misses from Table 3-2 is shown again in Figures 3-4 and 3-5. It can be seen that five out of the six vessels involved in collisions were self-takers but the vessel types as well as the pilotage situations were more diverse for the near misses.

![Figure 3-4, Pilotage situation for vessels involved in collisions (PLACID)](image)

![Figure 3-5, Pilotage situation for vessels involved in near misses (PLACID)](image)

Assumed incident cause

A number of the incident reports contain a short description in which the assumed main cause of the incident is sometimes mentioned. An overview of these assumed incident causes is given in Table 3-4. The table shows that the assumed incident cause was only noted for one situation. In this case the assumed cause for the collision was Carelessness, which is a control error.
More data was available for near misses. It can be seen that Control errors are to be blamed for twelve near miss situations, as opposed to only one External error (fog). For 11 near miss situations no assumed cause was given.

<table>
<thead>
<tr>
<th>Incident causes</th>
<th>Collision</th>
<th>Near miss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control error</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Carelessness</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Communication error</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Navigational error</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Manoeuvring error</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>External error</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Fog</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Mechanical error</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other technical failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 3-4, Assumed incident causes (PLACID)

Incident location

The two figures below indicate the locations of the various incidents occurring in the Port of London approach channels. A more detailed chart of this area, including the names of the various channels, as well as a figure indicating the vessel routes can be found in paragraph 4.3 Port of London approaches.

The collisions are shown as blue dots in Figure 3-6. As there were only three collisions, no conclusions can be made concerning their locations.

The near misses are shown as red dots in Figure 3-7. It can be seen that many of the near misses are concentrated in the Princes Channel as well as in the Oaze Deep area. The Princes Channel is a narrow area with shallow banks, which can cause navigational difficulties. The Oaze Deep area is the busiest area of the Port of London approaches, as various channels merge and then separate into the Thames and the Medway. There is no traffic separation scheme in this area and there is a lot of merging traffic.

Figure 3-6, Port of London approach channels - Locations of collisions (PLACID)
[MARICO MARINE, 2006]
3.3.2 SOS analysis

The Dutch Transport Research Centre made incident data available from the SOS database, from 1998 until 2004. Approximately 19% of minor ship incidents that occur in Dutch territorial waters as well as 68% of all major ship incidents are recorded in this database. In these seven years, 6323 incidents were recorded. Because of the large range of incident types and locations, many of these incident records are not relevant for the research currently being carried out. In order to come to useful conclusions it was therefore necessary to sort the data to isolate the relevant incidents.

The main focus of this report is on collisions that occur between vessels that are underway in restricted waterways. This means that groundings, contact with fixed objects, collisions with moored vessels and collisions involving manoeuvring vessels in restricted waterways will not be considered here. The database also contained six incidents occurring at sea. These will not be considered here.

After sorting, 788 relevant records of collisions between vessels underway were left. These were split up into two categories according to location: collisions occurring in port areas and collisions occurring in inland waterways. This distinction was made because the traffic characteristics in these areas are different. For example, sea-going vessels are present in port areas but not in inland waterways. Also, port areas generally consist of a network of navigation channels so that vessels can be involved in crossing situations, while vessels in inland waterways generally continue along the same channel, occasionally meeting or passing other vessels. However inland waterways also have a similar characteristic to certain port areas: the waters are confined and the vessels pass along navigation channels.

Each relevant record consists of a minimum of 343 data fields. For some records a number of data fields were left empty, indicating that the information was unavailable. It must be noted that the unavailability of certain information has possibly lead to some inaccuracies concerning the sorting of the data. Some irrelevant cases might have been left in the database or some relevant records might have been eliminated unintentionally.
The data fields that have been filled in provide information about the date, time and location of the incident, as well as about the weather conditions. Detailed information is also given about the vessels involved, the nature of the incident, and the damage as a result of the incident. Finally, an assumed main cause for the collision is given. Three main categories are identified: Control error (=human error), External error (=weather) and Mechanical error. These are each divided into a number of subcategories. It must be kept in mind that a main cause for a collision is not easily identified. Often many factors have played a part in the occurrence of the incident and it is often not clear which of these was the main cause. For each collision one of these factors has been identified as being the main cause. Appendix B gives a list of the data fields of the SOS database.

In the analysis of the SOS database, attention was paid to the following: vessel types involved in collisions, the weather conditions at the time of the collision (visibility, currents and wind) and the assumed main causes of the collision. These will each be discussed below.

Vessel type

The vessel types in the database can be divided into sea-going vessels and inland vessels. Table 3-5 on the following page gives the number of vessels of each type that have been involved in a collision.

At a first glance it may seem incorrect that a substantial number of sea-going vessels are involved in collisions in inland waterways. This is due to the definitions of waterways handled in the SOS database. Various long entrance channels to ports have been categorised as inland waterways.

Figure 3-8 shows the distribution of vessel categories in both inland waterways and port areas. Inland merchant vessels are involved in collisions most frequently, followed by the category Other inland vessels. These Other inland vessels consist mostly of pleasure craft such as sailing yachts and motor yachts, as can be seen from Table 3-5.
<table>
<thead>
<tr>
<th>Vessel category</th>
<th>Vessel type</th>
<th>Inland waterway</th>
<th>Port area</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea-going merchant vessels</td>
<td>Bulk carrier</td>
<td>14</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Chemical tanker</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Container vessel</td>
<td>19</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>General Cargo vessel</td>
<td>39</td>
<td>11</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Liquid gas tanker</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Tanker</td>
<td>9</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Passenger ferry</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>RoRo vessel</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Navy vessel</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>93</td>
<td>21</td>
<td>114</td>
</tr>
<tr>
<td>Other sea-going vessels</td>
<td>Service vessel</td>
<td>8</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Tow boat</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Fishing vessel</td>
<td>12</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>20</td>
<td>8</td>
<td>28</td>
</tr>
<tr>
<td>Inland merchant vessels</td>
<td>Container vessel</td>
<td>16</td>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>General Cargo vessel</td>
<td>460</td>
<td>50</td>
<td>510</td>
</tr>
<tr>
<td></td>
<td>Gas tanker</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Tanker vessel</td>
<td>188</td>
<td>19</td>
<td>207</td>
</tr>
<tr>
<td></td>
<td>Push / Tow boat with general cargo</td>
<td>95</td>
<td>3</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Push / Tow boat with tanker</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Passenger vessel</td>
<td>123</td>
<td>7</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>RoRo vessel</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Other (special transport/unknown)</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>901</td>
<td>86</td>
<td>987</td>
</tr>
<tr>
<td>Other inland vessels</td>
<td>Service vessel</td>
<td>8</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Push / Tow boat</td>
<td>8</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Fishing vessel</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Sailing yacht</td>
<td>151</td>
<td>14</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td>Motor yacht</td>
<td>161</td>
<td>8</td>
<td>169</td>
</tr>
<tr>
<td></td>
<td>Unspecified recreational vessel</td>
<td>51</td>
<td>3</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>383</td>
<td>36</td>
<td>419</td>
</tr>
<tr>
<td>Unknown vessel type</td>
<td></td>
<td>21</td>
<td>7</td>
<td>28</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>1418</td>
<td>158</td>
<td>1576</td>
</tr>
</tbody>
</table>

Table 3-5, Vessel types involved in collisions (SOS)

Figure 3-9 below shows a specification of the inland merchant vessel types involved in collisions in both inland waterways and port areas. General cargo vessels are most frequently involved in collisions in both locations, followed by tanker vessels.
Due to lack of traffic data of all Dutch inland waters it is not possible to comment on the likelihood of the various inland vessel types being involved in collisions.

Traffic data of sea-going vessels in the Port of Rotterdam is available and will be used to comment on the sea-going merchant vessel types involved in collisions in both inland waterways as well as port areas. It has been assumed that sea-going vessels recorded in inland waterways are in fact navigating in port approach channels. Although the Netherlands has a number of ports, the Port of Rotterdam is the largest one. For this research it has been assumed that the traffic data for the Port of Rotterdam is representative for all port areas in the Netherlands, although in reality each port has its own traffic patterns. The number of each vessel type arriving at the Port of Rotterdam in the period between January and December of 2005 is given in Table 3-6. The final two columns of this table indicate the number of vessels of each type that were involved in a collision. It must be noted that the numbers of collisions given in this table differ from the numbers in Table 3-5. This is because the vessel categories defined in the SOS database differ from those used in the traffic data of the Port of Rotterdam. For example, the SOS vessel categories Chemical tanker, Liquid gas tanker and Tanker have been combined in a single Tanker category. The statistics presented in Table 3-6 are also shown in Figure 3-10 on the following page.

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Number of arrivals</th>
<th>Percentage of arrivals</th>
<th>Number of collisions</th>
<th>Percentage of collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger vessel</td>
<td>23</td>
<td>0.1%</td>
<td>1</td>
<td>0.8%</td>
</tr>
<tr>
<td>Bulk carrier</td>
<td>1126</td>
<td>3.6%</td>
<td>15</td>
<td>11.7%</td>
</tr>
<tr>
<td>Tanker</td>
<td>7323</td>
<td>23.3%</td>
<td>23</td>
<td>18.0%</td>
</tr>
<tr>
<td>General cargo</td>
<td>9958</td>
<td>31.7%</td>
<td>50</td>
<td>39.1%</td>
</tr>
<tr>
<td>RoRo / passenger ship</td>
<td>4609</td>
<td>14.7%</td>
<td>1</td>
<td>0.8%</td>
</tr>
<tr>
<td>Container vessel</td>
<td>6728</td>
<td>21.4%</td>
<td>21</td>
<td>16.4%</td>
</tr>
<tr>
<td>Other vessels</td>
<td>10</td>
<td>0.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dredger</td>
<td>162</td>
<td>0.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offshore vessel</td>
<td>23</td>
<td>0.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research boats</td>
<td>11</td>
<td>0.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tug boat</td>
<td>433</td>
<td>1.4%</td>
<td>1</td>
<td>0.8%</td>
</tr>
<tr>
<td>Fishing boat</td>
<td>10</td>
<td>0.0%</td>
<td>16</td>
<td>12.5%</td>
</tr>
<tr>
<td>Non-classified vessel</td>
<td>1005</td>
<td>3.2%</td>
<td>1</td>
<td>0.8%</td>
</tr>
<tr>
<td>Total</td>
<td>3120</td>
<td>100.0%</td>
<td>128</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Table 3-6, Port of Rotterdam traffic data (January-December 2005) and collision statistics of sea-going merchant vessels

[www.portofrotterdam.com]

From Figure 3-10 it can be seen that General cargo vessels are most frequently involved in collisions, followed by Tanker vessels and Container vessels. It is also apparent that the percentage of collisions in which the vessel types Bulk tanker, General cargo and Fishing boats are involved is larger than the percentage of arrivals they represent. This indicates that these three vessel types are more likely to be involved in collisions than other vessel types. Of these three, it appears that fishing vessels are most likely to be involved in a collision, followed by Bulk carriers. It can also be seen that only one RoRo/passenger vessel was involved in a collision despite the fact that these vessels frequently call at the Port of Rotterdam. From this figure it appears that RoRo/passenger vessels are least likely to become involved in a collision.
Traffic data and collision data Port of Rotterdam

Figure 3-10, Port of Rotterdam traffic data and collision statistics of sea-going merchant vessels

Weather conditions

In total, four different weather conditions were considered for each collision in the database. These are light, visibility, wind speed and current. In the category light, a distinction was made between daylight, dark and dusk. The visibility is expressed in metres and has been divided into 5 categories. The wind speed is given in metres per second and is divided into 11 categories. A frequency table of wind speeds at Hoek van Holland in The Netherlands has also been given as a comparison. Finally 7 current categories are given. These are also expressed in metres per second. The numbers in Tables 3-7 to 3-9 indicate the number of collisions that occurred during each weather condition.

Table 3-7 shows that the majority of the collisions occurred in daylight rather than dusk or dark. For inland waterways this can be explained as inland vessels generally go to anchor during the night. However, it may be assumed that the arrival and departure of sea-going vessels in port areas are more regularly spread over 24 hours. It is not clear why the majority of collisions occurred in daylight.

In order to come to any valid conclusions concerning the actual influence on collision probability, statistics of the traffic distribution over daylight and dark are required.

<table>
<thead>
<tr>
<th>Light</th>
<th>Inland waterway</th>
<th>Port area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight</td>
<td>461</td>
<td>55</td>
</tr>
<tr>
<td>Dark</td>
<td>210</td>
<td>17</td>
</tr>
<tr>
<td>Dusk</td>
<td>21</td>
<td>6</td>
</tr>
<tr>
<td>Unknown</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>708</td>
<td>79</td>
</tr>
</tbody>
</table>

Table 3-7, Light conditions and collisions (SOS)

From Table 3-8 it appears that the majority of collisions occurred in conditions of good visibility. As the frequency of fog conditions are not known, it is not possible to conclude whether collisions are most likely to occur in conditions of poor visibility than in good visibility. However it is remarkable that so few collisions occurred in conditions of restricted visibility (65 collisions during visibility of less than 1000 metres). A study carried out by NISHIMURA, 2006 was previously mentioned in Chapter 2. In this study it was found that
restricted visibility had a significant negative influence on the encounter avoiding capacity of the navigator.

<table>
<thead>
<tr>
<th>Visibility</th>
<th>Inland waterway</th>
<th>Port area</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50 m</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>50 - 200 m</td>
<td>36</td>
<td>2</td>
</tr>
<tr>
<td>200 - 500 m</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>500 - 1000 m</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>&gt; 1000 m</td>
<td>424</td>
<td>45</td>
</tr>
<tr>
<td>Unknown</td>
<td>220</td>
<td>32</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>709</strong></td>
<td><strong>79</strong></td>
</tr>
</tbody>
</table>

Table 3-8, Visibility conditions and collisions (SOS)

Table 3-9 below shows that collisions most frequently took place in conditions of minimal current speeds. As no current data of the various areas is available, no conclusions can be reached concerning the influence of current speeds on the collision probability.

<table>
<thead>
<tr>
<th>Current</th>
<th>Inland waterway</th>
<th>Port area</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 m/s</td>
<td>267</td>
<td>28</td>
</tr>
<tr>
<td>1 - 5 m/s</td>
<td>201</td>
<td>3</td>
</tr>
<tr>
<td>6 - 10 m/s</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>10 - 15 m/s</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>16 - 20 m/s</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>21 - 25 m/s</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>26 - 30 m/s</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Eb tide, current unknown</strong></td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td><strong>Flood tide, current unknown</strong></td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Unknown</td>
<td>210</td>
<td>41</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>709</strong></td>
<td><strong>79</strong></td>
</tr>
</tbody>
</table>

Table 3-9, Current speeds and collisions (SOS)

A comparison of Tables 3-10a and 3-10b [www.knmi.nl] on the following page shows that the frequencies of wind speeds at Hoek van Holland generally coincide with the accident frequencies for the various wind speed categories. Two differences can be found: very low wind speeds rarely occur (0 to 1.9 m/s occur 5.73% of the time) but accidents do frequently occur in this wind speed range. And although wind speeds between 6.0 and 10.9 m/s often occur (43.01% of the time) fewer than 8% of all accidents take place in this wind speed range. Collisions appear to be more frequent in extremely calm weather with very low wind speeds (0 to 1.9 m/s, described as Calm to Light air on the Beaufort-scale) than in wind speeds varying from 6.0 to 10.9 m/s (Moderate breeze to Fresh breeze on the Beaufort-scale). This can be explained by the Bathtub Curve Theory according to which errors are frequently made if the workload is either very low or very high. Fewest errors are made in the case of an average workload. This theory is illustrated in Figure 3-11 below [BEIMERS, 2002]. Under such very calm circumstances the captains will feel relaxed and might not be as alert as they would be under more demanding circumstances.

Figure 3-11, Bathtub curve
Collision causes

In the SOS database many different collision causes were given. Some of these collision causes occurred frequently while other collision causes seldom occurred and had a more descriptive nature. These collision causes were divided into three main categories: Control errors (human errors), External errors and Mechanical errors. Not all of the collision causes were given such a category in the SOS database. These causes were placed in the categories that were found to be most suitable. It is important to realise that such a clear categorisation of incident causes does not truly exist. It can be argued that some of the External errors are in fact Control errors. For example, in situations of predicted dense fog it is up to the captain to take suitable safety measures such as reducing speed and consulting the radar more regularly. If he fails to do so and an accident occurs, it can therefore be considered a Control error rather than an External error.

The various causes and the number of collisions they apply to can be seen in Table 3-11 on the following page.

Figure 3-12 indicates the assumed incident categories of collisions occurring in both inland waterways and port areas. It is clear that control errors occur most often (69% of all recorded collisions). External errors and mechanical errors occur least frequently (10% and 6% respectively).
<table>
<thead>
<tr>
<th>Assumed main incident categories</th>
<th>Assumed main incident causes</th>
<th>Inland waterway</th>
<th>Port area</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control error (human error)</td>
<td>Careless navigation</td>
<td>181</td>
<td>199</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Navigational error</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maneuvering error</td>
<td>147</td>
<td>158</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incorrect procedure</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incorrect use of navigational aids</td>
<td>13</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Communication error</td>
<td>22</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Captain under the influence of alcohol</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Captain fell asleep</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pilot steering error</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blind spot</td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other control error</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not specified control error</td>
<td>112</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>495</td>
<td>50</td>
<td>545</td>
</tr>
<tr>
<td>External error</td>
<td>Poor visibility</td>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Heavy fog</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strong current</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heavy wind</td>
<td>23</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Storm</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heavy snowfall</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Suction generated by other vessel</td>
<td>14</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Suction generated by own vessel</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waves generated by other vessel</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waves generated by own vessel</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unspecified weather conditions</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>72</td>
<td>6</td>
<td>78</td>
</tr>
<tr>
<td>Mechanical error</td>
<td>Engine failure</td>
<td>20</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steering failure</td>
<td>21</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Failure navigational equipment</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other mechanical failure</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>44</td>
<td>3</td>
<td>47</td>
</tr>
<tr>
<td>Non specified / other error</td>
<td></td>
<td>98</td>
<td>20</td>
<td>118</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>709</td>
<td>79</td>
<td>788</td>
</tr>
</tbody>
</table>

Table 3-11, Assumed main incident causes (SOS)

Figure 3-12, Assumed main incident categories (SOS)
3.4 Chapter conclusions

In this chapter a detailed overview has been given of accident data obtained from the Port of London Authority Computerised Accident Database (PLACID) and the Dutch Transport Research Centre’s SOS database.

The conclusions of this accident data analysis are based on the assumption that a high representation of certain influencing factors in the accident databases implies that an accident is more likely to occur if these factors are present. In other words, the presence of such factors in the specific maritime traffic situation may be assumed to increase the collision probability. It is not known whether the presence of these factors in other maritime traffic situations will also influence the collision probability. Care must be taken if the conclusions in this chapter are to be applied to other situations.

The two databases handled in this research each have disadvantages. Although the PLACID database contains ten years of data, it contains only a very limited number of incidents due to the relatively small area it covers. Basing conclusions on a small amount of data can lead to invalid generalisations.

The SOS database on the other hand is very large and covers various areas, where circumstances such as the layout of the waterway and the mix of vessel types present are different. These circumstances can have a relevant influence on the incident probability. Due to the size of the database it was not possible to distinguish between different areas, apart from making a rough division between port areas and inland waterways. Therefore it is possible that invalid generalisations were made during the analysis of this data. It must also be remembered that the database only covers 68 percent of serious incidents that occur on Dutch territorial waters, which could mean that the statistics might not be entirely representative of the real situation. The coverage of the PLACID database is unknown, but as the area is small and the level of control is high, it may be assumed that no relevant incidents were left unrecorded.

The conclusions of the accident data analysis will be presented in the following order: vessel types, pilotage situation, weather situation, assumed collision cause and finally the incident location.

Vessel type

From the PLACID data it appeared that fishing vessels were more frequently involved in collisions in the Port of London area than other vessel types. General cargo vessels were most frequently involved in near miss situations. However if the Port of London traffic data is taken into account, it may be concluded that bulk carriers are most likely to become involved in a near miss situation in the Port of London area than other vessel types, followed by reefers and then container vessels. RoRo vessels and dredgers are least likely to become involved in an incident in this area.

The SOS data showed that of all vessel categories:
- Inland merchant vessels were most frequently involved in collisions
- Other inland vessels were second most frequently involved in collisions
- Sea-going merchant vessels were third most frequently involved in collisions

Of these Sea-going merchant vessels:
- General cargo vessels were most frequently involved in a collision
- Container vessels and bulk vessels were respectively second and third most frequently involved in a collision
After comparing the SOS collision statistics to traffic data for the Port of Rotterdam, it appeared that of the Sea-going merchant vessels:

- Fishing vessels and Bulk carriers are most likely to become involved in a collision in Dutch territorial waters
- RoRo/passenger vessels are least likely to become involved in a collision

The conclusions based on PLACID data and SOS data show similarities as well as differences. In both the Port of London area and the Dutch territorial waters bulk carriers are most likely to become involved in an incident. Also, in both situations RoRo vessels are least likely to be involved in an incident. But the vessel types that are second and third most likely to become involved in an incident are different in the Port of London area and the Dutch territorial waters.

These differences indicate that these conclusions are location-specific and may therefore not be applied to other locations. This conclusion is supported by the fact that the incident analysis carried out by PSARAFITS et al. in 1998 also produced different results, as can be seen in paragraph 2.6.

Consequently it must be remarked that the conclusions obtained from the SOS database might not be accurate as they are based on various different locations. A further investigation into separate incident locations such as the Port of Rotterdam and certain busy inland waterways is advisable in order to validate these conclusions.

Finally, it is uncertain whether collision and near miss statistics may be compared in this manner. It is possible that this is a reason for the differences in the results.

In the Port of London area, fishing vessels were most frequently involved in collisions. And in the Dutch territorial waters, Other inland vessels were very frequently involved in collisions (26.6% of all vessels involved in a collision were Other inland vessels). The category Other inland vessels includes service vessels and fishing vessels but the majority of these were pleasure craft, 21% of all vessels involved in collisions were sailing yachts and motor yachts.

Most of the current maritime traffic simulation programs are not able to include pleasure craft, fishing vessels and work vessels in the models as their movement is unpredictable and therefore difficult to model. These percentages are too high to be neglected and a solution must be found to include these vessels in risk assessments in the future.

Pilotage situation

The majority of vessels involved in collisions and near misses in the Port of London area are self takers. For near miss situations this number was closely followed by PEC’s and piloted vessels.

A self taker can be any type of vessel that does not require pilotage or a Pilotage Exemption Certificate (PEC). It is possible that the captains of these vessels have no knowledge of the area and might therefore be more focussed on navigating towards their destination than on collision avoidance which increases the probability of becoming involved in an encounter or a near miss.

Weather situation

Most collisions in Dutch waters occurred during normal conditions such as: daylight as opposed to night, good visibility as opposed to fog and low currents as opposed to rough waters. This can perhaps be explained by the Bathtub Curve Theory.
Assumed collision cause

For most collisions a combination of various collision causes can be discerned. In the PLACID data as well as in the SOS data only the single most apparent cause was mentioned. The results indicate that the most frequent causes of collisions and near misses are control errors, which are human errors (54% of PLACID incidents and 69% of SOS collisions). These errors can be caused by carelessness or poor capability of the captain of the vessel and his crew. Only a small number of collisions was caused by any type of mechanical failure (none of the PLACID incidents and 6% of SOS collisions). These results differ from the statement made in paragraph 2.6 that approximately 80 to 90 percent of all maritime incidents are caused by human errors. In the case of the PLACID database this can be explained by the fact that only a rough indication of the collision cause was provided so it is possible that a further investigation would lead to a similar percentage of human errors. And in the case of the SOS database, no collision cause was provided for approximately 15% of all collisions. It may therefore be assumed that the percentage of human errors is in fact slightly higher than 69%.

Location of incident

The majority of the incidents in the Port of London area are concentrated in two areas: in the narrow and shallow part of the Princes Channel and in the Oaze Deep area where there is a high intensity of merging and crossing traffic. However this statement is based on a small amount of data. More research can be recommended to find out whether the traffic intensity or the presence of navigational difficulties such as shallow areas influences the collision probability.

Summary

The aim of this chapter was to find the factors that have the greatest influence on the probability of a collision between vessels underway in restricted waters. As the PLACID database consists of a relatively small dataset, this review can be taken as indicative only. Of the factors investigated in this chapter, the vessel type and the assumed collision cause appeared to have the clearest influence on the collision probability. The influence of the pilotage situation, weather conditions and location on the collision probability appear to very weak and more research is required to come to any conclusions concerning these factors.
4 STUDY OF MARITIME TRAFFIC

4.1 Introduction

Much can be learned from the observation of maritime traffic. This chapter contains a study into maritime traffic aimed at answering the second research question posed in this thesis:

Which factors have the greatest influence on the Closest Point of Approach between vessels underway in restricted waters?

This study was based on four days of maritime traffic data of the Port of London approach area, collected between November 13th 2006 and November 16th 2006. This data was obtained using an Automatic Identification System (AIS), of which a description is given in the following paragraph. Paragraph 4.3 continues with a description of the Port of London approach area where the data was collected and paragraph 4.4 presents an analysis of this data. The collected AIS data can be used to identify and investigate encounter situations. A study of these encounter situations will provide insight into the navigational behaviour of vessels in restricted waterways, especially in the presence of other vessels. The AIS data is therefore suitable to be used in an investigation into the CPA between vessels in various traffic situations. It is desirable to learn more about the influence of various factors on the CPA as this can provide insight into the perceived level of safety and acceptable overtaking or crossing distances between vessels. This in turn can aid in the dimensioning of vessel safety domains for restricted waterways and also provide insight into factors that possibly influence the collision probability between vessels. The chapter ends with the conclusions of this analysis in paragraph 4.5.

4.2 Automatic Identification System (AIS)

For larger sea-going vessels (> 300 GT) and all passenger vessels it is mandatory to keep an Automatic Identification System (AIS) on board. AIS is an instrument which transmits information about the vessel to other vessels and to coastal authorities through dedicated VHS frequencies. Similarly, the AIS system picks up information from these other vessels. The information transmitted includes the vessel's name, its dimensions, the vessel type, registration numbers, cargo information, locations of departure and destination as well as the vessel's position, speed and heading. The data is transmitted at frequent intervals of approximately 2 to 10 seconds if a vessel is underway, depending on the speed at which the vessel is travelling, and approximately 3 minutes if a vessel is at anchor. Coastal authorities use AIS data for traffic management and security matters and captains on board vessels use the data as a navigational aid. AIS data can be used to calculate the Closest Point of Approach (CPA) and time to closest point of approach (TCPA) to any desired target [www.imo.org].

The Automatic Identification System has only recently been implemented. It was developed in 1997 in a close cooperation between the International Maritime Organisation (IMO), the International Association of Lighthouse Authorities (IALA), the International Telecommunications Union (ITU) and the International Electrotechnical Commission (IEC). A phased introduction of the system was carried out between the years 2000 and 2004 [NORRIS, 2007].

Besides its uses in traffic management and navigation, AIS is also a useful tool for carrying out traffic surveys. If an AIS transponder is fitted in a fixed location, it will pick up information transmitted by all vessels carrying an AIS system passing through the area. In this manner
AIS data covering the Port of London approaches was recorded by MARICO\(^3\) during various periods in 2006. In this chapter the AIS data of four days will be considered, from November 13\(^{th}\) 2006 to November 16\(^{th}\) 2006.

### 4.3 Port of London approaches

The Port of London consists of various terminals and berths located along the River Thames, from the mouth of the Thames at the East coast of the United Kingdom all the way to the centre of London. The area where the River Thames flows into the North Sea is called the Thames Estuary and this area is characterised by many different channels and shallow banks. Only a few of these channels are sufficiently straight, wide and deep enough to be suitable for navigation. The main approach channels to the River Thames and the Port of London are called the Princes Channel, the Knock John Channel and the Barrow Deep. These channels merge in an area called the Oaze Deep. Together, these waters are called the Port of London approaches. From the Oaze Deep vessels can continue to the West, either along the Thames towards the Port of London or along the Medway, where the Medway Ports are located. The Admiralty Chart of this area is given in Figure 4-1. The magnified area is where the AIS data was collected. Figure 4-2 shows the vessel tracks that were recorded between November 13\(^{th}\) and November 16\(^{th}\) 2006. The tracks of eastbound vessels departing from the Port of London are indicated in blue and the red lines indicate the westbound vessels heading towards the Port of London.

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\(^3\) MARICO Marine and Risk Consultants Ltd.
4.4 Analysis of AIS traffic data

The AIS traffic data of the Port of London approaches that was collected by MARICO can be represented either in tabular format or graphically, using the programs Microsoft Visual FoxPro and MapInfo respectively. Both formats were used in the investigation into CPA’s. These programs are capable of sorting the AIS traffic data and selecting the tracks of vessels that have come within a certain distance to one another. This option was used to select relevant situations of which to take the CPA into account. Initially only encounter situations were considered. No collisions occurred during the four days of data collection.

In FoxPro the distance between vessels is measured radially from the precise location of the AIS transponder on each ship. However, an encounter has previously been defined as a situation in which the safety domains of two vessels overlap. These safety domains are not circular but rectangular and are expressed in terms of multiples of the ship length and ship width. In order to identify encounters, the program was used to select all situations in which two vessels had come within a distance of 400 metres to each other (measured from the exact location of the AIS transponder on each vessel). FoxPro is able to show the safety domains around the vessels involved in these close quarter situations. Each of these situations was then manually evaluated to identify the real encounters.

The vessel safety domains that were used cover an area of three times the ship length in front of the vessel, one time the ship length behind the vessel and half of the ship width on either side of the vessel. An example of such a vessel safety domain is given in Figure 4-3 below. These dimensions were taken from MARTRAM, Royal Haskoning’s maritime traffic simulation program. For tanker vessels a larger safety domain was applied, covering an area of 16 times the ship length in front of the vessel, 8 times the ship length to the rear of the vessel and 2 times the ship width on either side of the vessel.

Using these vessel safety domains it appeared that a total of nine encounters occurred in the Port of London approaches area during the four days considered. However, one of these encounters occurred between two manoeuvring vessels in an anchorage. As this research
excludes manoeuvring vessels this situation was not taken into account. The eight remaining relevant encounters are discussed in paragraph 4.4.1.

In addition to these encounters, a number of other remarkable and possibly hazardous traffic situations was recognised. These will be discussed briefly in paragraph 4.4.2 as they can also aid in understanding common navigational behaviour.

4.4.1 Encounter situations

Table 4-1 gives the available details of the eight relevant encounter situations that were identified from the AIS data. The locations of these encounters are shown in Figure 4-4.

<table>
<thead>
<tr>
<th>Encounter number</th>
<th>Date</th>
<th>Vessel name</th>
<th>Vessel type</th>
<th>Vessel length (m)</th>
<th>Course (degrees)</th>
<th>Speed (knots)</th>
<th>Traffic situation</th>
<th>Minimum CPA (m)</th>
<th>Channel width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13/11/2006</td>
<td>AGISILAOS</td>
<td>Tanker</td>
<td>184</td>
<td>102</td>
<td>10.7</td>
<td>Crossing</td>
<td>381</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SUNNANHAV</td>
<td>Cargo</td>
<td>115</td>
<td>271.8</td>
<td>13.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>14/11/2006</td>
<td>BRITTA ODERN</td>
<td>RoRo</td>
<td>170</td>
<td>270.7</td>
<td>14.6</td>
<td>Overtaking</td>
<td>180</td>
<td>1090</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DART4</td>
<td>RoRo</td>
<td>160</td>
<td>272.5</td>
<td>14.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>14/11/2006</td>
<td>BRITTA ODERN</td>
<td>RoRo</td>
<td>170</td>
<td>271.7</td>
<td>14.7</td>
<td>Parallel</td>
<td>89</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DART4</td>
<td>RoRo</td>
<td>160</td>
<td>275.7</td>
<td>14.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>14/11/2006</td>
<td>BRITTA ODERN</td>
<td>RoRo</td>
<td>170</td>
<td>270.7</td>
<td>14.6</td>
<td>Overtaking / crossing</td>
<td>322</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M V LOUISE RUSS</td>
<td>Cargo</td>
<td>170</td>
<td>250</td>
<td>16.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>14/11/2006</td>
<td>ANETTE THERESA</td>
<td>Tanker</td>
<td>130</td>
<td>101</td>
<td>11.6</td>
<td>Overtaking</td>
<td>265</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TRANS BOTNIA</td>
<td>Cargo</td>
<td>154</td>
<td>107.4</td>
<td>19.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>14/11/2006</td>
<td>MONSOON</td>
<td>Tanker</td>
<td>100</td>
<td>281.1</td>
<td>10.9</td>
<td>Overtaking</td>
<td>380</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BETTY THERESA</td>
<td>Tanker</td>
<td>115</td>
<td>272.7</td>
<td>11.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>16/11/2006</td>
<td>BETTY THERESA</td>
<td>Tanker</td>
<td>115</td>
<td>90.9</td>
<td>13.58</td>
<td>Overtaking</td>
<td>198</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DART9</td>
<td>RoRo</td>
<td>170</td>
<td>92.58</td>
<td>17.43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>16/11/2006</td>
<td>MONSOON</td>
<td>Tanker</td>
<td>100</td>
<td>92.8</td>
<td>12.9</td>
<td>Overtaking</td>
<td>156</td>
<td>810</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SIGAS</td>
<td>Tanker</td>
<td>276</td>
<td>91.1</td>
<td>12.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>COMMANDER</td>
<td>Tanker</td>
<td>27</td>
<td>91.1</td>
<td>12.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4-1, Summary of encounter situations

Figure 4-4, Encounter locations in Port of London approaches
The extent to which these encounters could be analysed depended on the availability of information. Therefore the analysis of factors influencing the CPA was limited to the five factors in the table above: vessel type, vessel dimensions, vessel speed, channel width and traffic situation. Other possible factors such as pilotage conditions and weather conditions were not taken into consideration due to lack of data.

The traffic situations mentioned in Table 4-1 were identified using Figure 4-5 below in which meeting, crossing and overtaking situations are defined [HOEK, 1999]. These definitions are based on the COLREGs.

![Figure 4-5, Definition of various traffic situations](image)

Each of the 8 encounter situations in Table 4-1 will now be discussed in more detail.

**Encounter 1**

Figure 4-6 below shows a situation in which the westbound cargo vessel Sunnanhav crossed behind the eastbound tanker Agisilaos. Their vessel safety domains overlapped although neither vessel actually entered the safety domain of the other vessel. The red dots in the figure indicate the approximate locations of the AIS transponder on board the vessels at the time of the encounter. This is an indicator of the location of the vessels within the safety domains shown. The minimum CPA between the two vessels was 381 metres.

![Figure 4-6, Encounter 1 (Sunnanhav and Argisilaos, 13-11-2006)](image)
Encounters 2 and 3

Figure 4-7 shows the two encounters that occurred between the RoRo vessels Dart 4 and Britta Oden. The two vessels were both entering the Princes Channel in westbound direction and remained very close to one another for approximately half an hour. Within this period of time, their safety domains overlapped twice, their CPA first being 180 metres and then 89 metres.

(Encounter 2 is on the right of the figure and encounter 3 on the left.)

Figure 4-7, Encounters 2 and 3 (Britta Oden and Dart4, 14-11-2006)

Encounter 4

In between encounters 2 and 3, a third vessel also entered the same area and became involved in an encounter. Figure 4-8 below shows a number of encounters that occurred at the Eastern entrance to the Princes Channel. The various colours of the vessel domains indicate different time periods. The green domains represent the situation around 03:00 on the 14th of November. From this figure it can be seen that the cargo vessel MV Louise Russ passed in front of the Britta Oden and Dart 4 as they entered the Princes Channel. During this manoeuvre, the safety domains of the MV Louise Russ and the Britta Oden overlapped. The minimum CPA during this event was 322 metres.

Figure 4-8, Various encounters at the entrance to the Princes Channel (14-11-2006)

Encounter 5

The pink coloured domains in Figure 4-8 above indicate the tanker vessels Annette Theresa and Trans Botnia. The rear ends of their domains overlapped as they were leaving the Princes Channel in easterly direction at 04:50 but neither vessel entered the safety domain of the other vessel. The recorded CPA between the two vessels was 265 metres. But the vessels were diverging so it may be concluded that the CPA recorded at the time of the encounter was greater than the CPA earlier on during the overtaking manoeuvre.
Encounter 6
The two tanker vessels Monsoon and Betty Theresa were both heading into the Princes Channel at 22:40 as the front of their safety domains overlapped. Neither vessel entered the safety domain of the other vessel. At the moment of the encounter their CPA was 380 metres. The Monsoon and the Betty Theresa are indicated in red in Figure 4-8 above.

Encounter 7
The tanker vessel Betty Theresa and RoRo vessel Dart 9 shown in Figure 4-9 were both eastbound inside the Thames as they were about to enter the Oaze Deep. The Dart 9 was overtaking Betty Theresa and the front parts of their safety domains overlapped as the vessels passed through the bend, where the deep part of the navigation channel is very narrow. Their minimum CPA was 198 metres.

Encounter 8
The tanker Monsoon overtook the Sigas Commander as they were heading east inside the Princes Channel, causing a minimum CPA of 156 metres. The AIS connection was lost so there is no image available of the precise moment of the encounter. Figure 4-10 below shows the situation minutes before the encounter was registered. This figure indicates that the Monsoon was slowly moving back towards the starboard side of the navigation channel after having overtaken the Sigas Commander. It may be assumed that neither vessel entered the safety domain of the other vessel but that the front parts of the two safety domains overlapped.

The Dart 3 is also present in this figure. The Dart 3 overtook the Sigas Commander on its starboard side while Monsoon was overtaking it on its port side. The Dart 3 was not involved in an encounter however it may be remarked that such an overtaking manoeuvre is not a safe situation.

Two of these eight encounters were categorised as crossing situations, the other six were overtaking situations. No meeting situations occurred in the period considered. In an overtaking situation both vessels are required to navigate in the starboard half of a two-way
navigation channel whereas in meeting situations the entire width of the navigation channel is generally available. Therefore encounters and other interesting occurrences are most likely to occur in overtaking situations.

As no relevant differences in CPA were found between the crossing and meeting situations, these traffic situations will not be considered separately in the following analysis.

Below, the factors vessel type, vessel dimension, channel width and vessel speed of these encounter situations are discussed in order to investigate possible relationships between these factors and the Closest Point of Approach.

Vessel type and vessel dimension
Of the 16 vessels involved in these encounters, 3 were cargo vessels (approximately 19%), 6 were RoRo vessels (approx. 38%) and 7 were tankers (approx. 44%). These values can be compared to the traffic data in the area in order to determine which vessel types are most likely to be involved in an encounter.

Table 4-2 shows the number of merchant vessels that passed through the Port of London approach channels during the 4 days under consideration. Pilotage vessels, tugs, fishing vessels and recreational vessels are not included in these numbers and neither are vessels underway to or from an anchorage. This distinction has been made for the benefit of the investigation in Chapter 5 as these vessel types cannot be modelled in maritime traffic simulation programs.

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Number of vessels</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo vessel</td>
<td>104</td>
<td>36.9%</td>
</tr>
<tr>
<td>Dredger</td>
<td>30</td>
<td>10.6%</td>
</tr>
<tr>
<td>General cargo</td>
<td>7</td>
<td>2.5%</td>
</tr>
<tr>
<td>RoRo vessel</td>
<td>92</td>
<td>32.6%</td>
</tr>
<tr>
<td>Tanker vessel</td>
<td>43</td>
<td>15.2%</td>
</tr>
<tr>
<td>Unknown</td>
<td>6</td>
<td>2.1%</td>
</tr>
<tr>
<td>Total</td>
<td>282</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Table 4-2, Traffic through Port of London approaches, 13-11-2006 to 16-11-2006

From this table it can be seen that 36.9% of the relevant vessels passing through the Port of London approach channels are cargo vessels and only 19% of the vessels involved in an encounter were cargo vessels. This indicates that cargo vessels are less likely to be involved in encounter situations than RoRo vessels, which make up for 32.6% of all relevant vessels and 38% of all encounters. Tanker vessels appear to be most likely to be involved in an encounter as only 15.2% of all vessels account for 44% of all encounters.

These numbers differ from the conclusion about vessel types in the Port of London approaches presented in paragraph 3.4, where it was stated that bulk carriers were most likely to be involved in near misses, followed by reefers and container vessels. RoRo vessels and tanker vessels appeared to be least likely to be involved in a near miss situation in the Port of London area.

A few possible explanations can be given for this difference. First of all, it must be remembered that the captains on board RoRo vessels are generally PEC holders. This implies that they are familiar with the area. It is possible that smaller CPA’s are accepted before an encounter is registered as an incident if a RoRo vessel is involved. Secondly, the vessel safety domain used to identify encounters for tankers is very large. It is significantly larger than the encounter criterion handled for other vessel types. It is generally known that tanker vessels carry hazardous substances and it is therefore advisable that they keep a larger distance with respect to other vessels. However, there is no prescribed vessel safety
domain especially for tanker vessels. It is possible that the vessel safety domain used in this investigation was larger than the domain that is used in real life, resulting in the identification of more encounters involving tankers.

The fact that relatively few tanker vessels were involved in a near miss situation according to the PLACID database (see Table 3-2) can be an indication that the definition of a near miss situation handled by the Port of London Authority differs from the definition of an encounter used in this chapter. The definition of a near miss situation that is handled by the Port of London Authority can be found in Appendix D-1. It is clear that no distances are mentioned and the classification of a near miss is therefore subjective. If these definitions are indeed different, the encounter numbers are not directly comparable however each of these situations clearly indicates the distances that captains find acceptable. This knowledge can be used in the definition of vessel safety domain dimensions. Finally it must be kept in mind the findings in this chapter are based on only four days of AIS data whereas the PLACID database covers a period of ten years. This can also be a cause for inconsistencies between both conclusions, as seasonal variations and annual developments are not taken into account in this chapter.

Figures 4-11 and 4-12 below show scatter plots in which the CPA’s of the encounter situations are plotted against the vessel lengths and vessel widths respectively for various vessel types. No relationship is clear between the vessel lengths and CPA’s. Nor is a relationship visible between the vessel widths and CPA’s.

![Figure 4-11, Vessel types, lengths and CPA’s](image)

![Figure 4-12, Vessel types, widths and CPA’s](image)

Channel width

Figure 4-13 below shows the CPA and the channel width of all eight encounter situations. From this figure it is clear that in all encounters apart from encounter number 7, the CPA is significantly smaller than the channel width. Encounter 7 took place in a very narrow and bendy section of the navigation where the channel width was only 300 metres. In this case
the vessels were using the entire available channel width. A similar finding was mentioned by COLDWELL, 1983: ‘traffic flows within the Humber seaway suggested that marine traffic did not use the available sea room to its greatest advantage.’

![Figure 4-13, Encounter CPA’s and Channel widths](image)

A second figure was made in which the vessel widths were also taken into account. In Figure 4-14 the CPA’s are plotted against the available channel width, which was calculated by subtracting the two vessel widths from the total channel width at the location of the incident. No clear relationship is visible. These two figures imply that the vessels are comfortable in navigating at such short distances to one another, irrespective of their size and even though more sea space was available for them to have kept more distance. Various possible explanations can be proposed for this behaviour. This level of comfort might be caused by the fact that many of the captains are familiar with the area and perhaps even with each other. However it must also be kept in mind that many of these vessels are navigating under time pressure from their managing companies so the captains have to make a trade off between the shortest and the safest route. Finally, a closer look needs to be taken at the precise locations of these encounters as it is possible that some of the vessels were depth restricted and therefore were in fact forced to accept such small CPA’s relative to the total channel width.

![Figure 4-14, Available channel width and CPA’s](image)

Vessel speed
Figure 4-15 below is a scatter plot in which the CPA’s of the encounter situations are plotted against the vessel speeds for various vessel types. What is remarkable in this figure is that the CPA for cargo vessels decreases as the vessel speed increases. This is contrary to expectation. This relation is based on only three vessels so this relationship might prove to be invalid if more data is considered. No relationship is visible for RoRo vessels or tankers.
Traffic situation
Six out of the eight recorded encounters concerned overtaking situations, and only two were crossing situations. This can be explained by the layout of the Port of London approach channels. These consist of a network of navigation channels and there are only limited areas where crossing situations are possible. In these crossing areas such as the Oaze Deep the traffic intensity is high, so a number of crossing situations leading to encounters could have been expected. The fact that they did not occur often might indicate that the Port of London VTS have actively managed the traffic to avoid such situations where possible.

No meeting encounters occurred in the period considered. This can be explained by the fact that two ‘lanes’ are generally available in meeting situations. This means the vessels are not required to navigate as close to one another as they are in overtaking situations where both vessels navigate in a single ‘lane’.

A significant number of encounters involving tankers occurred as they were altering course in a turning manoeuvre, for example in a bend. Either the front or the back of the long vessel safety domains overlapped as they ‘swept’ over one another. It could be argued that the situation is in fact not hazardous if the rear ends of both vessel safety domains overlap, as the vessels are navigating away from each other. However, making such a statement would require more research.

4.4.2 Other situations
Besides the eight encounter situations that were analysed above, a number of other interesting navigational situations occurred between the 13th and 16th of November. These will each be discussed below.

The first situation occurred between the RoRo vessel Dart 9 and the cargo vessel Samskip Courier on the 13th of November. This is shown in Figure 4-16 below. Both vessels were westbound inside the Princes Channel. At first they were navigating close together, having a minimum CPA of 222 metres. The Samskip Courier navigated along the channel edge, while the Dart 9 crossed over into the port side of the channel. They then started to merge again. All this time both vessels were navigating at approximately 10 knots and neither vessel showed any intention of trying to overtake the other vessel.
The next interesting situation involved three vessels navigating alongside in the Princes Channel for several minutes as can be seen in Figure 4-17. They were all eastbound. The Dart 3 seems to have passed in between the Sand Weaver and the Forth Fisher. The minimum CPA between the Sand Weaver and the Dart 3 was 87 metres and the minimum CPA between the Dart 3 and the Forth Fisher was 110 metres. In this situation the Sand Weaver crossed over into the port side of the channel. The average channel width at this point was 950 metres. Although no encounter occurred here, it is certainly not a desirable situation from a safety point of view.

The Britta Oden and the Dart 4 were involved in encounters 2 and 3 which were briefly described in the previous paragraph. Figures 4-18 and 4-19 below show their vessel tracks over a period of more than an hour. Just before entering the Princes Channel, the Dart 4 (track indicated by pink numbers) approaches the Britta Oden (track indicated by red numbers) at high speed, with the apparent intention to overtake. However the captain of the Dart 4 seems to realise that he will not be able to complete the manoeuvre before entering the Princes Channel. The Dart 4 is overtaking and therefore the give-way vessel, so it reduces speed and enters the Princes Channel behind the Britta Oden. Both vessels stay very close to one another throughout their passage to the Oaze Deep.
The final situation of interest is a meeting situation. This was the only meeting situation in all four days that met with the selection criterion, being a radial distance between vessels of 400 metres. The westbound tanker Anette Theresa and the eastbound cargo vessel Hoo Falcon were navigating in the Princes Channel where the width was approximately 970 metres. Their CPA was 116 metres. It is clear from Figure 4-20 below that the Anette Theresa is navigating on the port side of the channel. As the area is shallow it may be possible that the Anette Theresa was trying to navigate in the deepest part of the channel. It is not known whether the Port of London VTS or the crew of the Hoo Falcon were informed of the intention to do so. The Anette Theresa was travelling at a speed of 12.5 knots and the Hoo Falcon was travelling at a speed of 8.5 knots. In a meeting situation the relative speed between two vessels is often very high.
4.5 Chapter conclusions

The aim of this chapter was to analyse the collected AIS information in order to find factors of influence on the Closest Point of Approach between vessels in the Port of London approach channels. The data available provided the opportunity to investigate the influence of vessel type and dimension, vessel speed, channel width and traffic situation. It is obvious that each situation is unique, however an attempt was made to discover certain trends in them.

Vessel types
No relationship was found between the vessel types and the CPA. It did appear that tanker vessels are more likely to be involved in encounters in the Port of London approaches than RoRo vessels. Cargo vessels are least likely to be involved in an encounter in this area. This conclusion differs from the conclusion about vessel types in the Port of London approaches presented in paragraph 3.4, where it was stated that RoRo vessels were least likely to be involved in near misses. A number of possible explanations can be given for this difference. First of all, the vessel safety domain used to identify encounters for tankers is very large. It is significantly larger than the encounter criterion handled for other vessel types. It is generally known that tanker vessels carry hazardous substances and should therefore keep a larger distance with respect to other vessels. However, there is no prescribed vessel safety domain especially for tanker vessels. It is possible that the vessel safety domain used in this investigation was larger than necessary, causing more encounters involving tankers to be identified.

The fact that relatively few tanker vessels were involved in an encounter according to the PLACID database (see Table 3-2) can be an indication that the definition of a near miss situation used by the Port of London Authority differs from the definition of an encounter handled in this chapter. The definition of a near miss situation that is used by the Port of London Authority can be found in Appendix D-1. It is clear that no distances are mentioned and the classification of a near miss is therefore subjective. Finally it must be kept in mind that the conclusions reached in this chapter are based on a very limited amount of data.

Vessel dimensions
No clear relationships were found between the vessel length and vessel width and the CPA.

Channel width
No relationship was found between the channel width and the CPA. Vessels seemed to be comfortable navigating very close to one another although there appeared to be enough sea space available for them to keep a larger distance. More investigation is required to find the reasons for this behaviour.

Vessel speed
No clear relationship was found between the vessel speed and the CPA for RoRo and Tanker vessels. It appeared that the CPA for cargo vessels decreased as the vessel speed increased. This is contrary to expectations as speeds are usually only increased in safe situations, where there is sufficient sea space to keep a reasonable distance from other vessels. But as this finding was based on only three situations, it could merely be a coincidence rather than a trend. More situations need to be considered to either support or dismiss this conclusion.
Traffic situation
Six out of the eight recorded encounters concerned overtaking situations, two were crossing situations and no meeting encounters occurred. This can be explained by the layout of the Port of London approach channels.

The Other situations presented in paragraph 4.4.2 included vessels navigating abreast for long periods of time, overtaking manoeuvres in narrow waters and three vessels navigating abreast. These illustrate that vessels often consciously enter into possibly hazardous situations although there is no need for them. The captains who carry out such manoeuvres must be comfortable in doing so, which again might be explained by the fact that the captains are familiar with the area and also with each other.

General conclusions

The investigation of the AIS data did not lead to the identification of any relationships between CPA’s and certain influencing factors. In this chapter the AIS data of four days was investigated. This is a limited amount of data, therefore the investigation of a larger amount of data is required in order to find whether such relationships are present. If relationships between CPA’s and influencing factors can be identified from a larger set of AIS data it must be investigated whether they may be generally applied to the Port of London area at all times.

It must be remarked that the encounters investigated in this chapter were defined by the vessel safety domains used. Had these domains been larger or smaller, respectively more or fewer encounters would have been found which could have lead to different conclusions.

This is especially true in the case of tanker vessels, of which the vessel safety domain is very large. In this chapter it was found that two encounters occurred when the rear end of a tanker vessel domain ‘swept’ over the domain of another vessel. It can be questioned whether these situations are in fact hazardous as the vessels are navigating away from each other in well-defined navigation channels.
This leads to the question whether the use of vessel safety domains is suitable for areas of restricted waters, especially in areas with well-defined navigation channels such as the Port of London area. The theory of vessel safety domains was developed for the use on open waters and is therefore not capable of discerning situations in which vessels are required to come close to one another in restricted waters but do not pose a threat.

It would perhaps be more suitable to use vessel safety domains of which the size and shape vary according to the dimensions and layout of navigation channels. It is not clear how such vessels safety domains could be implemented in maritime traffic simulation models. This requires further research.

The conclusions of this chapter might also have been different had data been used for other days due to (seasonal) variations in weather and traffic intensity have not been taken into consideration.
It can be recommended to collect more data and to continue research on this topic.
5 MARITIME TRAFFIC SIMULATION PROGRAM

5.1 Introduction

This chapter will address the final research question posed in this thesis:

What is the reliability of MARTRAM, the maritime traffic simulation program used by Royal Haskoning to qualitatively analyse maritime safety in restricted waters using the method of encounters?

MARTRAM is short for Marine Traffic Risk Assessment Model. This program was developed in-house by Royal Haskoning in 1992 and it has been used in various projects since. MARTRAM was developed for risk assessment and capacity study purposes, for present as well as future maritime traffic situations. In the most recent project, MARTRAM was used to model the Port of London approach channels in order to investigate the relative maritime safety of a number of channel improvement designs. This is the same area for which AIS data from MARICO is available. This created a good opportunity to evaluate the model made in MARTRAM. The reliability of the model and the program can be investigated by comparing the results of MARTAM simulations to the original traffic data recorded by AIS. The capabilities and restrictions of MARTRAM are similar to those of other existing maritime traffic simulation programs that are based on the theory of vessel safety domains. An evaluation of MARTRAM will therefore be indicative of the quality of these programs in general.

This chapter begins with a general description of the maritime traffic simulation program MARTRAM, followed by a description of the model of the Port of London approach channels in paragraph 5.3. In paragraph 5.4 the input of the model is presented. Next, the MARTRAM results and the AIS data are combined in paragraph 5.5 and this chapter ends with the conclusions of this evaluation in paragraph 5.6.

5.2 MARTRAM

MARTRAM can be used to simulate various maritime traffic situations. In order to do so, a specific model needs to be made in the program. This can be done in the following manner:

Navigation channels are represented by nodes which are joined by segments. Each of these nodes can be assigned properties such as channel width, and segments can be given a certain speed limit which applies to all vessels passing through the segment. A channel can be suitable for either one-way or two-way traffic. Once the various nodes and segments are in place, MARTRAM requires that routes are defined, indicating where traffic flows are possible.

After a model of the traffic situation has been created, the traffic data for 24 hours must be inserted into the program. First the various vessel types should be defined, as each type has characteristic dimensions, speed and vessel safety domain. The default setting of MARTRAM includes a 25% variation in vessel length and a 10% variation in vessel speed around the inserted values. It is possible to define two different vessel safety domains for each vessel type: one for full speed and one for a speed of 4 knots. This data can be inserted in the ‘Vessel properties input screen’ shown in Figure 5-1.
Next, the number of vessels passing along each route in the model must be inserted along with each of their departure times. MARTRAM uses two hour time-slots within which the vessels’ departure times are randomly distributed. As a result of this, the traffic situation produced in MARTRAM will not be identical to the specific day that is used as input. An example of a ‘Route properties’ input screen is shown in Figure 5-2. In this example, two ‘Cargo 160’ vessels pass along the route every 24 hours, which comes to a total of 730 ‘Cargo 160’ vessels annually. The departure time of the first vessel is randomly distributed between 02:00 and 04:00 and the departure time of the second vessel is randomly distributed between 14:00 and 16:00 as can be seen in the lower part of the screen, where a timescale with two-hour intervals is shown for 7 days. Although only 24 hours of traffic data is inserted into the model, MARTRAM carries out simulation runs of 7 consecutive days using this same data. Due to the randomness of the vessel departure times, the results of each of these 7 days will each be slightly different.

During a simulation run vessels are generated in the starting points of a route. These vessels make their way along the predefined routes, maintaining a set distance with respect to the centreline of the navigation channel all throughout the simulation run. This distance is defined relative to the total channel width therefore it changes as the channel width increases or decreases. This distance is randomly generated from the distribution given in Figure 5-3 for every vessel passing through the model. The default setting shown assumes that the majority of the vessels remain in the starboard side of the channel, in accordance with the COLREGs. A small number of vessels will navigate along the centre of the channel or perhaps even slightly into the port side.
As the vessels each pass along their respective routes, MARTRAM keeps track of the distances between the different vessels. All vessels are assigned a so-called observation domain, which functions as the arena described in paragraph 2.5: when another vessel is detected within the observation domain of a vessel, a collision avoidance manoeuvre is activated. In MARTRAM this collision avoidance action consists of a reduction in vessel speed while the vessel maintains its course. The dimensions of this observation domain are set to be 5% greater than the forward vessel safety domain and 10% wider than the vessel safety domain. These values cannot be changed by the program user.

MARTRAM counts the number of times that the safety domains of two vessels overlap during each simulation run. Such an occurrence is called an encounter. Every time an encounter occurs, the time and location of the encounter as well as the vessel types involved are saved in an excel file which can be consulted after the 7-day simulation run is completed. A screenshot is also made and saved for each encounter that occurs. In this way each encounter can be analysed after completion of the simulation. An example of such a screenshot is given in Figure 5-4. This figure shows an encounter that has occurred where a route separates into two branches. The nodes and segments that form the routes are visible,
as well as the actual vessels which can be seen inside the rectangular vessel safety domains.

The simulation runs can be carried out in real time or up to 60 times real time. The available speeds are 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, 30 and 60 times real time. MARTRAM provides full display of the entire simulation. It is possible to zoom in or out of the model before the start of a simulation, so that specific areas can be observed in more detail as required.

More information about MARTRAM can be found in Appendix A-2.

5.3 Model of Port of London Approaches

In 2006, MARTRAM was used to model the Port of London approach channels. The layout of this model is shown in Figure 5-5 below. Appendix C contains a number of figures in which the various routes of the model have been highlighted.

In Figure 5-5 it can be seen that the route along the Princes Channel is very narrow. The reason for this is that the Princes Channel passes through a shallow area and only a narrow part of it has sufficient depth for deeper drafted vessels to pass through. It can also be seen that many navigation channels merge in the Oaze Deep area, which is the busiest area in the Thames Estuary.
By definition, a model can never be completely identical to the situation in reality. Simplifications and assumptions will always have to be made when creating a model. The simplifications that were made in the creation the MARTRAM model of the Thames Estuary are stated below.

- Although the Oaze area is up to 1.4 nautical miles (approximately 2600 metres) wide at places, it is assumed that the vessels stay within 2 one-way navigation channels of 1000 metres width (see Figure 5-5). The vessels are assumed to bear to starboard when navigating in this area. The northernmost channel is for westbound traffic and the southernmost channel is for eastbound traffic.
- It may occur that a vessel is required to pick up a pilot near the Oaze Deep. This requires a significant decrease in vessel speed and plenty of sea space. A separate pilotage route was inserted in order to put local speed restrictions on individual vessels. A speed limit of 6 knots is valid for all vessels passing along this route. This route is indicated in Figure 5-5.
  The Pilotage Regulations for the Port of London define which vessels are required to pick up a pilot along this route. The relevant excerpt of these Regulations is given in Appendix D-2.
- No route has been made to drop off pilots. Pilot boardings and landings near the Oaze Deep are very rare and it was decided to keep the model as simple as possible.
- There is a number of sections where all vessels are assumed to slow down to 6 knots due to limited available depth or channel width or other navigational hazards. These locations are indicated in Appendix C.

5.4 Model input

The input of the MARTRAM model consists of the AIS traffic data recorded by MARICO for four days, from the 13th of November 2006 until the 16th of November 2006. This is the same data that was analysed in the previous chapter. In order to input this data into MARTRAM, the data was sorted and tables were produced of the traffic passing through each of the five starting points of the routes in the model. These points are indicated as purple dots in Figure 5-5 above. To facilitate the insertion of this data into MARTRAM, the data was then sorted per route. Appendix E-1 contains an excel sheet of the traffic data for each route in the model. These sheets contain AIS information such as the departure time, destination, vessel name, vessel category, vessel dimensions and vessel speed.

In MARTRAM a number of vessel types were defined, each based on vessel categories and dimensions from the AIS data. An overview of these vessel types is given Appendix E-2, along with their length, width and speed. Also, each vessel type is assigned a safety domain which is expressed as a multiple of the vessel length and width. These vessel safety domains were defined during the set-up of the model by Royal Haskoning and their dimensions have previously been given in Chapter 4.

Not all of the AIS traffic data provided was complete so a number of assumptions had to be made with regard to the input of the model. For example, the AIS data contained a number of vessels entering the modelled area but not exiting the area. These vessels are assumed to have gone to an anchorage where they remained until the following day. MARTRAM is not capable of modelling such behaviour. In MARTRAM the vessels can only continue along the various channels at a set speed, therefore these anchored vessels have been left out of the model. Also, pilot cutters, tugs and dredgers at work have not been included in the model due to the unpredictability of their tracks as they do not follow set routes. For a number of
vessels, the vessel dimensions were not given or appeared to be incorrect. These dimensions were checked using other available sources of information such as the Internet. For some vessels the dimensions were not found. These dimensions were estimated based on the dimensions of other vessels of the same vessel type. Finally, in the model no distinction was made between vessels carrying hazardous cargo or marine pollutants and vessels carrying “normal” cargo. Vessels carrying hazardous cargo or marine pollutants are required to keep a greater distance with respect to other vessels. In other words, they have a larger vessel safety domain. However the AIS traffic data did not include information about the loads carried.

After this data was inserted into MARTRAM six separate simulation runs were carried out for each of the four days for which input data was available. The results of these 24 runs will be discussed in the following paragraph.

5.5 MARTRAM evaluation

This paragraph contains an evaluation of the MARTRAM model of the Port of London. This evaluation is based on the comparison of the model to the real situation in the Port of London approaches of which AIS traffic data is available. It must be remembered that the AIS traffic data was not yet available when the MARTRAM model was developed.

First the accuracy of the model’s layout was analysed. Figure 5-6 below shows all vessel tracks recorded by AIS, indicating the flow of traffic through the area. A comparison of these tracks to the MARTRAM model in Figure 5-7 showed that these two were fairly similar. The most obvious differences were found in the Oaze Deep area, where the model discerns two different routes along the north and south of the Oaze Deep. In reality vessels also passed through the centre of this area. Also the route from the south of the Oaze Deep into the Barrow Channel appeared to be located slightly too far to the East in the model. Another noticeable difference was found in the area to the West of the Oaze Deep, where there is no distinguishable pilot route in reality. This is because the precise location of pilot boarding is very dependent on the local weather conditions so it varies for each individual case. Finally, the vessel tracks at the eastern end of the Princes Channel fan out into various directions but the MARTRAM model consists of a single straight and narrow route.

![Figure 5-6, AIS vessel tracks in Port of London approaches](image)
The second part of the MARTRAM evaluation was based on the program output which consisted of a number encounters. As was described in the previous chapter, the AIS data can be arranged to also show encounter situations. A comparison was made between these two numbers of encounters to indicate the reliability of the MARTRAM model. This comparison had to be held on a statistical level because it was not possible to compare individual encounters. This was due to the aforementioned two-hour time slot, which limits the chances that an encounter occurs at any particular location or between any particular vessels.

Due to the differences between the model and reality described in the previous paragraph, it cannot be expected that the MARTRAM model will generate the same number of encounters as occurred in reality. However, if the ratio between the AIS encounters and MARTRAM encounters is found to be similar for the various days of data, it can be used in the safety study into alternative situations. This ratio will enable the translation of the MARTRAM output to an expected number of encounters in the new situations. But this ratio is only valid for alternative situations that are based on the same real situation for which encounter data is available. For the investigation of other situations, encounter data needs to be available and this ratio must be defined again.

Table 5-1 below contains a summary of the MARTRAM output for four days, starting on the 13th of November 2006. For each day the first column gives the total number of encounters calculated during a 7-day run in MARTRAM and the second column gives the average number of encounters per day. The complete MARTRAM output can be found in Appendix F.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Average</td>
<td>Total</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>encounters per day</td>
<td>encounters</td>
<td>encounters per day</td>
<td>encounters</td>
</tr>
<tr>
<td>Run 1</td>
<td>57</td>
<td>8.14</td>
<td>81</td>
<td>11.57</td>
</tr>
<tr>
<td>Run 2</td>
<td>44</td>
<td>6.29</td>
<td>79</td>
<td>11.29</td>
</tr>
<tr>
<td>Run 3</td>
<td>47</td>
<td>6.71</td>
<td>68</td>
<td>9.71</td>
</tr>
<tr>
<td>Run 4</td>
<td>26</td>
<td>3.71</td>
<td>70</td>
<td>10.00</td>
</tr>
<tr>
<td>Run 5</td>
<td>51</td>
<td>7.29</td>
<td>83</td>
<td>11.86</td>
</tr>
<tr>
<td>Run 6</td>
<td>40</td>
<td>5.71</td>
<td>82</td>
<td>11.71</td>
</tr>
<tr>
<td>Average</td>
<td>6.31</td>
<td>11.02</td>
<td>8.19</td>
<td>10.86</td>
</tr>
</tbody>
</table>

Table 5-1, MARTRAM encounter results
From this table it can be seen that the variation in encounters is large, for the various runs as well as for the four different days. For example on the 13th of November 57 encounters occurred during the first run but only 26 occurred during the fourth run. This is a decrease of more than 50%. This variation is caused by a number of factors such as the element of randomness in the vessels departure times and the variations in vessel dimensions, vessel speeds and vessel tracks.

The variation in encounters calculated for the different days also depends on the difference in input. The fewest encounters were calculated on the 13th, and the most encounters were calculated on the 14th. This reflects the variation in traffic intensity of the input, the 13th having the least traffic and the 14th being the busiest day. This can be seen in the MARTRAM input given in Appendix E-1.

The number of real encounters that were identified from the AIS data is shown in Table 5-2 below, together with the averages of the MARTRAM encounters. The ratio between the two is also given, which is defined as the number of AIS encounters divided by the number of MARTRAM encounters.

<table>
<thead>
<tr>
<th>Date</th>
<th>MARTRAM</th>
<th>AIS</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>13/11/2006</td>
<td>6.31</td>
<td>1</td>
<td>0.16</td>
</tr>
<tr>
<td>14/11/2006</td>
<td>11.02</td>
<td>5</td>
<td>0.45</td>
</tr>
<tr>
<td>15/11/2006</td>
<td>8.19</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>16/11/2006</td>
<td>10.86</td>
<td>2</td>
<td>0.18</td>
</tr>
<tr>
<td>Average</td>
<td>9.10</td>
<td>2.00</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Table 5-2, Comparison of MARTRAM and AIS encounters

This table shows that there is a large difference between the number of encounters calculated by MARTRAM and the number of encounters identified by AIS. As it has already been pointed out, the model of the Port of London approaches resembles the situation in real life but it is by no means identical, and these differences can have an effect on the results. In MARTRAM all traffic is assumed to stay within set channels whereas in real life vessels have a greater freedom to navigate. Smaller vessels can manoeuvre outside channels if necessary and from Figure 5-6 it is obvious that vessels navigate over the entire area of the Oaze Deep. This concentration of traffic in the MARTRAM channels could lead to an increased number of encounters.

Another reason for the high number of encounters in MARTRAM is that the program does not take human behaviour into account. MARTRAM is capable of simulating a limited form of encounter avoidance behaviour, however the observation domain is small which limits the effectiveness of the encounter avoidance manoeuvre that is carried out. Also, as this encounter avoidance manoeuvre only consists of a reduction in speed, it will frequently not be sufficient to in fact avoid the encounter.

These results imply that human beings play a large part in the avoidance of encounter situations as they are able to anticipate traffic situations in advance and carry out manoeuvres such as changes in course and speed to avoid encounters. This anticipation consists of keeping a good lookout as well as the communication between captains and with the VTS staff of the Port Authority. Finally, it must be stated that these ratios are based on a very small dataset and might therefore not be representative for the general situation.

Table 5-2 shows that no encounters occurred on the 15th of November 2006. The ratios for the 13th and the 16th of November appear to be similar, but the ratio for the 14th is significantly larger. The ratio between the average number of AIS encounters and the average number of MARTRAM encounters was 0.22.
A comparison can also be made between the locations of the encounters. Figure 5-8 below shows the number of MARTRAM encounters that have occurred at various locations during the first two runs of each day.

![Figure 5-8, MARTRAM encounter locations](image)

From this figure it appears that there is quite a large variation in encounter frequencies at each location. For instance at node N56, one run generated 11 encounters per week and another run generated 36 encounters per week. Despite these variations, it is possible to identify a number of especially hazardous nodes where most encounters occurred. The five busiest nodes in the model are node numbers N56, N19, N28, N4 and POL. The locations of these nodes can be seen in Figure 5-9. The locations of the eight AIS encounters from Chapter 4 are also shown in this figure. It can be seen that node N19 and node POL coincide with the locations of AIS encounters 1 and 7. The model made in MARTRAM did not take the apparently busy and hazardous traffic situation to the East of the Princes Channel into account as it consisted of only a single channel instead of multiple channels merging from various directions. The reason for this is that the model was built to investigate the situation inside the Princes Channel rather than at its entrance.

![Figure 5-9, MARTRAM and AIS encounter locations](image)
The vessel types involved in encounters were also evaluated based on the results presented in Table 5-3. In this table, the first column for each day gives the average number of each vessel type that passed through the model during the six 7-day simulation runs that were carried out. The second column indicates the average number of each vessel type that was involved in an encounter during the six simulation runs.

Figure 5-10 shows the vessel types that were involved in an encounter, expressed as a percentage of the number of that vessel type passing through the model. This percentage was found by dividing the values in the second columns of Table 5-3 by the values in the first columns.

This figure demonstrates that the percentage of vessels involved in an encounter is approximately 20%. Tanker vessels appear to be involved in encounters more frequently. This can be explained by the large vessel safety domain of tanker vessels. On the 16/11/2006, more than half of the unknown vessels were involved in an encounter. This is a very high percentage compared to the other vessel types and also compared to the other days. The reason for this is not clear.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo vessel</td>
<td>224</td>
<td>40.7</td>
<td>259</td>
<td>56.2</td>
</tr>
<tr>
<td>Dredger</td>
<td>35</td>
<td>3.7</td>
<td>56</td>
<td>8.3</td>
</tr>
<tr>
<td>General cargo</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>1.0</td>
</tr>
<tr>
<td>RoRo vessel</td>
<td>105</td>
<td>21.5</td>
<td>105</td>
<td>33.8</td>
</tr>
<tr>
<td>Tanker vessel</td>
<td>77</td>
<td>22.5</td>
<td>91</td>
<td>54.7</td>
</tr>
<tr>
<td>Unknown</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>1.5</td>
</tr>
<tr>
<td>Total per 7-day simulation</td>
<td>441</td>
<td>88.4</td>
<td>525</td>
<td>155.5</td>
</tr>
</tbody>
</table>

Table 5-3, Vessel types involved in MARTRAM encounters

Finally, these vessel types can be compared to the vessel types that were involved in the real-life encounters registered by AIS. Of the 16 vessels involved in these encounters between November 13th and November 16th 2006, 3 were cargo vessels, 6 were RoRo vessels and 7 were tankers. This large share of tanker vessels is also clear from the MARTRAM results, however the relatively high number of RoRo vessels involved in real-life encounters is not visible in the MARTRAM output. In order to comment on the other vessel types, AIS data for a longer period will need to be considered.
5.6 Chapter conclusions

In this chapter the reliability of MARTRAM was evaluated, based on the model of the Port of London approaches. It appeared that the layout of the channels in the model resembled reality although the model was conservative in the Oaze Deep area as well as in the area to the East of the Princes Channel. The channels in the Oaze Deep area could be widened to cover the entire area and the channel to the East of the Princes Channel could also be widened to account for the traffic coming from and going in various directions.

The number of encounters calculated by MARTRAM appeared to be significantly larger than the number of encounters that were actually identified from the AIS data. A possible reason for this is the small observation domain handled in the program, which does not allow for enough time for effective collision encounter manoeuvres to be carried out. It can be recommended to increase the size of this observation domain to allow for more timely collision avoidance manoeuvres. It is also advisable to explore the possibilities of including course alterations to increase the effectiveness of these manoeuvres and their similarity to reality.

The output of the model showed a large variation in the number of encounters as well as the locations of these encounters. This indicates that the random elements included in the model have a significant influence on the output.

A desired result of this chapter would have been to find a ratio between the number of encounters generated by MARTRAM and the encounters registered by AIS. The variation in this ratio appeared to be very large (from zero to 0.45) so it was not possible to derive a single ratio. More traffic data will need to be collected in order to investigate both the variation in real life encounters and the variation in MARTRAM encounters.

MARTRAM was developed as a tool to analyse the relative maritime safety of various designs by comparing the number of encounters occurring in each. The large variations in results over the different simulation runs of the same situation are not very beneficial to this end, as variations between different alternatives might not be clear. MARTRAM is a detailed program in the sense that it takes many variations into account. This is an advantage, as the program tries to represent reality as closely as possible and it is capable of reflecting possible future variations. However the program may be more suitable for comparing various alternatives if certain variations such as the two-hour time slot were left out. In this way, it is possible to see the precise influence of the different alternatives on the traffic in terms of the number of encounters.
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Chapter 2 Maritime safety assessment
- It is necessary to develop a more accurate method for determining quantitative maritime collision probability. This requires the definition of vessel safety domains specifically for restricted waterways as well as an increased insight into various influencing factors on collision probability, especially human behaviour during navigation.

Chapter 3 Maritime incident data
- The vessel type and the assumed collision cause have the clearest influence on the collision probability between vessels underway in restricted waters.
  - Vessel type:
    - In the Port of London area fishing vessels were involved in collisions more frequently than other vessel types.
    - The vessel type most likely to become involved in a near miss situation in the Port of London area is bulk carriers.
    - The vessel category most likely to become involved in a collision in the Dutch territorial waters is Inland merchant vessels.
    - The Sea-going merchant vessel types that are most likely to become involved in a collision in the Dutch territorial waters are fishing vessels and bulk carriers.
  - Assumed collision cause:
    - Human errors are the most frequently occurring assumed collision cause in the Port of London area as well as in Dutch territorial waters.
- The influence of the pilotage situation, weather conditions and location on the collision probability appear to be very weak.

Chapter 4 AIS traffic data
- In the Port of London approaches encounters are most likely to occur in overtaking situations.
- In the Port of London approaches, tanker vessels are more likely to be involved in encounters than RoRo vessels.
- No relationships were found between the vessel type and the CPA or between the vessel speed and the CPA.
- No relationship was found between the CPA and the vessel length or between the CPA and the vessel width.
- Vessels generally navigate closer to one another than necessary. For most encounters the CPA was considerably smaller than the available channel width.
- Using existing vessel safety domains for the identification of encounters is possibly not a suitable method in restricted waterway situations.

Chapter 5 Maritime traffic simulation program
- It was not possible to find a single ratio between the number of encounters simulated by MARTRAM and the number of AIS encounters. More research will have to be carried out in order to prove whether such a ratio exists or not.
- MARTRAM cannot be used to determine the absolute level of safety of a maritime traffic situation.
- If MARTRAM is to be used to analyse the relative safety of various alternative traffic situations, it is advisable to include more possibilities concerning collision avoidance and to decrease the level of variations present in the program.
- However, in the long run the development of a more detailed maritime traffic simulation program is desired.

The conclusions of this thesis indicate that the topic of maritime collision probability is very complex and extensive. They also show that obtaining useful conclusions through research is a very time consuming task which demands the availability of large amounts of high quality data. The availability of advanced technical equipment such as bridge simulators is also required.

It must not be forgotten that a vast amount of research has already been done in this area, of which only a small amount has been highlighted in this report. It is important to combine and use all of this available knowledge in the next step forward.

It was found that existing maritime traffic simulation programs are not able to accurately model collision probability. Also doubts were expressed about the suitability of using vessel safety domains for the identification of encounters in areas of restricted water.

The recommendations given in the following paragraph indicate the steps that can be taken towards the development of an improved maritime traffic simulation program.

6.2 Recommendations

- Much information was found concerning vessel safety domains in open waters, but hardly any research seems to have been carried out into vessel safety domains in restricted waters. This is very relevant for safety assessments of port areas and inland waterways. In this thesis doubts have been expressed as to whether or not the existing version of vessel safety domains is suitable for use in restricted waters. More research is recommended into vessel safety domains suitable for restricted waters.

- It can also be recommended to look into possibilities of implementing vessel safety domains with varying shapes and sizes depending on the traffic situation. Factors such as channel dimensions and layout as well as vessel courses will need to be taken into consideration. It may be assumed that this is feasible using existing computer systems.

- A detailed study of AIS images could assist in the definition of vessel safety domains for restricted waters. Besides the investigation of CPA’s such as was done in this thesis, it can be recommended to also consider the vessel tracks before the actual moment of encounter. It would be very informative to identify the decision-making point at which an encounter avoiding manoeuvre is started. Such a study will provide more insight into the dimensions of vessel safety domains. This decision-making point can also be incorporated in maritime traffic simulation programs.

- It appeared that work vessels, fishing vessels and recreational vessels were involved in a significant number of near misses and collisions in the areas considered, but no maritime traffic simulation program exists which takes these individual vessels into account. It is recommended to carry out more research into possible ways to include these vessel types in future maritime traffic programs.

- In this study only a limited number of influencing factors on maritime incidents were investigated. Other factors such as vessel manoeuvring characteristics, hydrodynamic influences, level of traffic management, towage situations and the background, education and experience of vessel crew will need to be investigated further.
- This study only briefly touched on the influence of pilotage situation, weather conditions and location on collision probability. More data is required in order to investigate these issues.

- Collisions occur due to a combination of various causes. In this study only the assumed main collision cause was investigated. It is likely that certain causes are related. Research into the combination of various causes and their influence on the collision probability is recommended.

- The number of encounters generated by MARTRAM appeared to be significantly larger than the number of encounters occurring in reality. A possible reason for this is the limited measures for collision avoidance included in the program. It is recommended to develop MARTRAM to enable the user to vary the dimensions of the observation domain. If this domain is increased, the collision avoidance manoeuvres can be started at an earlier moment and fewer encounters will occur. Also, the options for the collision avoidance manoeuvres can be developed to include vessels altering course.

- In this report no ratio was found between the number of MARTRAM encounters and the number of AIS encounters. More traffic data will need to be investigated in order to find out whether such a ratio exists.

- It is possible that a ratio between the number of MARTRAM encounters and the number of AIS encounters does not exist due to the large variations in MARTRAM output which are caused by the set-up of the program.
In that case it can be recommended to adapt the program, for example by enabling exact vessel departure times to be inserted instead of the two-hour time slots presently used in the program.

- Other developments in the MARTRAM program that can be recommended are:
  o Inclusion of work vessels, fishing vessels and recreational vessels in the program. Research is required to find possible methods to do so.
  o Including the option of local speed variations for individual vessels so that pilotage activities such as slowing vessels for boarding and landing of pilots can be modelled. It should also be possible to model vessels going to and coming from anchorages.
  o Adapting the program so that it is capable of modelling grounding situations. Research will be required to investigate the possibilities of taking water depths and tidal effects into account.
  o Including variations in vessel tracks so that each vessel changes its location with respect to the centre of the channel rather than staying at a set distance throughout the simulation run. This will require a more detailed study into real vessel tracks.
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