Ship-Ship Collision Probability of the Crossing Area between Helsinki and Tallinn

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1 Introduction

Marine traffic is continuously increasing in the Gulf of Finland. In particular, growing number of oil tankers navigating in the gulf is raising concern in coastal countries. Russia is building new oil terminals and oil transports via the Gulf of Finland are estimated to increase even up to 250 millions of tons annually by 2015. The risk of an oil accident in the gulf is significant and continuously growing. In 2005, the Baltic Sea, and the Gulf of Finland as a part of it, was categorized as a Particularly Sensitive Sea Area (PSSA) by International Maritime Organization (IMO). An oil disaster would be devastating for its vulnerable nature. Careful risk analysis of the gulf should be fulfilled. [1][2][3][4]

Several reports concerning grounding and collision risks in the Gulf of Finland have been made, e.g. references [5], [6] and [7], but the overall risks of maritime transportation remain to be estimated. It is important to be aware of present risks to dimension needed preventive action and to be sufficiently prepared to possible oil and other accidents. The current risk level also has to be known to estimate the future change in it due to increasing traffic. It is not enough to know that the risk level of maritime transports in the Gulf of Finland is rising. More exact information about the magnitude of the rise is needed to dimension preventive action precisely enough. Strong reasoning is also needed to motivate the investment that safety measures require.

The aim of this paper is to present criteria for a good ship-ship collision model and then to reason why one of the three presented models is selected to be applied to the crossing area between Helsinki and Tallinn. This area is selected for this paper as it is one of the high accident risk areas of the Gulf of Finland [7]. Another objective is to consider how collision risk is changing in the future. Traffic data of 2006 is used to calculate collision probability and an estimate for collision probability in 2015 is made to evaluate the magnitude of increase in risk level.

This paper concentrates on the collision risk of a limited area between Helsinki and Tallinn. The risk of other maritime accident types is out of the scope. Other accident types include collisions with a bridge, quay or floating object, fire, explosions, leakings, storm damages and capsizings. However, groundings and ship-ship collisions are the most frequent maritime accident types in the Gulf of Finland [8]. In the scope of the probability of ship-ship collisions, the probabilities of head-on, overtaking and intersection collisions are not analysed in this paper. The latter may occur if a
ship omits to change course at the bend of the waterway and as a result collides with another vessel. [9]

This paper continues as follows. In Chapter 2, a literature review of modelling crossing collision probability is presented, and criteria for a good model are discussed. Pedersen’s collision model [10] is found to be the most suitable model for the purpose of this paper. Chapter 3 is about applying the chosen model with help of recorded AIS data to the crossing area of two waterways between Helsinki and Tallinn. The collision probability in 2006 is calculated and the probability for 2015 is evaluated with estimated future traffic. Finally, Chapter 4 contains discussion and conclusions.

2 Predicting the Frequency of Marine Accidents

Traditionally, casualty statistics have been analysed to get the average accident rates. Statistics give valuable information but cannot be used for all needed purposes. Regulations, ship structures and traffic flows continuously change and thus the past cannot be used to directly predict the future. When analysing a delimited geographical area, accident data is also too scarce to indicate the probability of severe accidents. So far, e.g. no catastrophic oil accident has occurred in the Gulf of Finland. However, it does not mean that the probability of such an accident would be zero. In addition, there are some problems with statistics, like data about accidents that is stored differently in variable databases. As a result, all information is difficult to put together. These are the essential reasons why rational risk calculation is needed. [10]

In this Chapter, the concepts of risk and risk analysis are presented first in Section 2.1. Subsequently, the common model for calculating marine accidents is presented in Section 2.2. Then, in Section 2.3, the author defines criteria for assessing different ship-ship collision models that are presented in Section 2.4. The proposed collision models are evaluated against made criteria in Section 2.5. Finally, Section 2.6 focuses on causation probability that is needed when any of the three presented collision models is applied.
2.1 Concepts of Risk and Risk Analysis

In Probabilistic Risk Analysis (PRA) and Probabilistic Safety Analysis (PSA), a risk is defined as the product of the probability of the unwanted event and of the consequences of the event if it occurs:

\[ \text{a risk} = \text{the probability of the event} \times \text{the consequences of the event} \]

The probability is often defined as the number of events per time unit, for example as the probability of the number of collisions per year. The costs describing the seriousness of the consequences might be for example lost human lives in a year or the cost of cleaning oil spills in a year. The objective of risk analysis is to find out what might happen, how probable it is and what are the consequences. In this paper, the focus is on the probability of the harmful event. E.g. references [10], [11], and [12] contain analysis about the consequences of ship-ship collisions. [11][13]

2.2 General Manner to Calculate the Probability of Marine Accidents

Typically, marine accident probabilities are modelled based on the work of Fujii et al [14] and Macduff [15]. The three collision models that are presented later in Section 2.4 do not make a difference. The common thing with the approaches is that the probability of an accident is defined as

\[ P = N_a \times P_c, \]

where \( N_a \) is the geometrical probability or the probability of being on a collision/grounding course. In other words, \( N_a \) accidents would occur if no aversive manoeuvres were ever made. \( P_c \) is the so-called causation probability or the probability of failing to avoid the accident while being on a collision/grounding course. A ship being on a collision/grounding course is called an accident candidate. An accident candidate may result in an accident for example because of a technical fault or human error. Causation probability quantifies the proportion of cases when an accident candidate ends up grounding or colliding with another vessel. Causation factor for ship-ship collisions is presented in detail in Section 2.6.
2.3 Criteria of a Good Model for Assessing Collision Probability

In this Section, the author defines criteria to estimate models for predicting the frequency of crossing collisions. Later, in Section 2.5, collision models found from literature are evaluated against these criteria.

A good collision probability model does not rely too much on statistics. The model should make past collision numbers look probable but changes in regulations, conditions, ship structures and traffic flows should affect the results got from the model. Again, past cannot predict the future and many, at least the previously mentioned, issues change the collision probability. A good model is robust, for example small changes in parameters got by expert estimations should not change results significantly. A good model is not too complicated and is easy to use. In addition, it takes into account the large variety of marine traffic as size and velocity of different ship groups vary notably. E.g. average value of vessel size does not give a sufficient picture of the diversity of real traffic flow. Besides, different ships also have dissimilar capability to avoid other vessels.

2.4 Alternative Collision Models

In the following, three different collision models are presented. More precisely, the models of Pedersen [10], Fowler and Sørgård [16], and Macduff [15] are covered.

2.4.1 Pedersen's Model

In the model of Pedersen [10], a crossing of two waterways is considered as illustrated in Figure 1. The model gives the geometrical collision probability meaning ships that would collide if no aversive manoeuvres were made. Two vessels arriving to the crossing area are contemplated. The ship in the waterway 1 approaches the ship in the waterway 2 with relative velocity that is formulated in the following way:

$$V_j = \sqrt{\left(V_i^{(1)}\right)^2 + \left(V_j^{(2)}\right)^2 - 2V_i^{(1)}V_j^{(2)} \cos \theta},$$

where $V_i^{(1)}$ is the velocity of vessel in ship class i in the waterway 1, $V_j^{(2)}$ is the velocity of ship class j in the waterway 2 and $\theta$ is the angle between incoming directions of vessels as shown in Figure 1. For calculations, ships are classified to groups by their type and length.
Pedersen [10] defines geometrical collision diameter (see Figure 2) as

\[
D_{ij} = \frac{L_i^{(1)} V_j^{(2)} + L_j^{(2)} V_i^{(1)}}{V_{ij}} \sin \theta + B_j^{(2)} \left\{ 1 - \left( \sin \theta \cdot \frac{V_j^{(1)}}{V_{ij}} \right)^2 \right\}^{1/2} + B_i^{(1)} \left\{ 1 - \left( \sin \theta \cdot \frac{V_j^{(2)}}{V_{ij}} \right)^2 \right\}^{1/2},
\]

where \(L_i^{(1)}\) is the length of vessel in ship class \(i\) in the waterway 1, \(L_j^{(2)}\) is the length of vessel in ship class \(j\) in the waterway 2. Equally, \(B\) is the width of vessel.
The number of collision candidates during studied time period is

\[
N_u = \sum_i \sum_j \int_{\Omega(z_j)} \int \frac{Q_{i\beta}}{V_i} f_i^{(1)}(z_i) f_j^{(2)} V_j D_j dA \Delta t
\]

(1)

where \(Q_{i\beta}\) is the number of movements of ship class \(\beta\) in the waterway \(\alpha\) per considered period of time \(\Delta t\). \(z_j\) is the distance from the centreline of the waterway 2. The lateral distribution of traffic of considered ship class in the considered waterway is denoted \(f\). Often a Gaussian distribution is used:

\[
f_j^{(2)}(z_j) = \frac{1}{\sigma_j^{(2)} \sqrt{2\pi}} \exp \left( -\frac{(z_j - \mu_j^{(2)})^2}{2\sigma_j^{(2)}^2} \right),
\]

where \(\mu_j^{(2)}\) is the mean value of \(z_j\) and \(\sigma_j^{(2)}\) is the standard deviation of \(z_j\). The number of collision candidates given by equation (1) need to be multiplied by causation factor (see Sections 2.2 and 2.6) to get the probability of a collision.

### 2.4.2 Model of Fowler and Sørgård

The collision model of Fowler and Sørgård [16] evaluates the frequency of ship-ship powered collisions. Powered collision signifies that collisions of drifting ships are not taken into consideration in their model. The frequency of encounters, \(n_{co}\), is calculated assuming that traffic movements are uncorrelated. Each encounter is multiplied by the probability of a collision per encounter, \(p_{co}\), to give the collision frequency, \(f_{co}\). The critical situation denotes that two ships are crossing within half a nautical mile of each other. Encounter frequency at a location estimated by a pair-wise summation across all shipping lanes. Calculation may either be done to all vessels or it is possible to take into account only some specific ship types. The collision frequency, \(f_{co}\), of the studied location is determined as

\[
f_{co} = n_{co} (p_c P_{co,c} + p_f P_{co,f}),
\]

where \(p_c\) and \(p_f\) are the probabilities of clear and reduced visibility. \(P_{co,c}\) and \(P_{co,f}\) are the probabilities of collision given an encounter in clear or reduced visibility.
2.4.3 Macduff's Model

The model of Macduff [15] is based on molecular collision theory. All vessels are supposed to navigate with the average speed of ships. A ship is expected to approach a shipping lane on a course that makes an angle $\theta$ with the lane. In reference [15], mean free path of a ship is defined as the distance which the ship can proceed, on average, before colliding with one of the vessels navigating along the main shipping lane. This train of thought ends to geometrical collision probability of

$$P_c = \frac{XL \sin \theta / 2}{D^2 925},$$

where $D$ is average distance between ships (density measure, in miles), $X$ is the actual length of path to be considered for the single ship (nautical miles) and $L$ is average vessel length.

2.5 Qualities and Drawbacks of the Presented Models

In the following, the presented collision models are evaluated against the criteria defined in Section 2.3. Basically, all models take into account the increase of traffic. Changes in regulations (for example new Traffic Separation Schemes) and conditions (for example visibility) must be integrated in causation factor in all the considered models.

First, the author analyses Fowler’s and Sørgård’s model. The collision candidates of their model are not all real collision candidates as all of the ships in encounter situation of the model would not collide even though the crews of the involved ships were asleep and did nothing. The number of encounters is still relative to actual collision candidates. Ships passing each other at close quarters need definitely to pay attention to each other’s movements as one of the ships may for example make a critical mistake and, as a result, collide with another ship but this has to be quite rare when compared to the situation of two ships approaching each other and then colliding. The manner of the model to calculate the amount of collision candidates is questionable but it is taken into account in the related causation probability which is smaller than causation factors used with other collision models (see Section 2.6). The paper does not suggest how to actually calculate the described geometrical collision probability. The model of Fowler and Sørgård makes possible to calculate collision probabilities for different ship groups. However, for example ship dimensions should be integrated in causation factor as the number of encounters does not change according to the ship size. It is good that the model takes into account different visibility conditions.
Macduff’s model does not take into consideration the differences between ships. Traffic is considered as continuous uniform flow and not as single ships with their individual characteristics as type, dimensions and velocity. Real marine traffic is not consisted of ships of equal size moving at equal velocity at equal distances from each other which makes the model imprecise.

Pedersen’s model defines collision candidates geometrically and the characteristics of the ships approaching each other are taken into consideration in the model. Changes in for example vessel size directly affect the results got from the model. Also collision probabilities of different ship groups can be calculated with the model. Collision candidates would really collide with each other if nothing was done to prevent the accident. In addition, the model is applied in many recent publications, for example in references [17], [18], [19], and [20].

The model of Pedersen seems to be the most suitable one for estimating collision risk of the considered area between Helsinki and Tallinn. Macduff’s model appears to be the least appropriate. More aspects are included in the geometrical collision probability of Pedersen’s model than of the model of Fowler and Sørgård. Pedersen’s model can be easily adjusted to changes in traffic situation or in other changing circumstances in the future. If wanted in the future, the proposition of the model of Fowler and Sørgård to take visibility conditions into account can be applied to Pedersen’s model as well. So Pedersen’s model is chosen to calculate collision probabilities for the purpose of this paper.

2.6 Causation Probability

The geometrical collision probabilities got from any of the earlier presented models have to be multiplied by a causation probability $P_c$ to get the probability of collision. Causation probability is the probability of failing to avoid the accident while being on a collision/grounding course. It can be estimated in two ways: by scenario approach or by synthesis approach. Scenario approach is used if $P_c$ is calculated on the basis of available accident data. For example Pedersen [10] suggests that $P_c$ can be estimated from accident data collected at various locations and then transformed to the analysed area. The advantages of this approach are its simplicity and related robustness.

In synthesis approach, specific error situations are supposed to occur in the vessel. They may cause an accident if they take place before or at the same time with a critical situation. Probability of error situations ($P_c$) is found by application of a Bayesian Belief Network or by use of a fault tree.
Bayesian networks are graphical representations of uncertain quantities. They show the dependence between different factors by an acyclic net of nodes and directed arcs. For example whether, speed of vessel, and stress of navigator are relevant factors in a Bayesian network model for causation factor in ship-ship collisions. For detailed explanation of use of Bayesian Belief Networks, see e. g. reference [21]. Bayesian Networks are used for the calculation of causation factor for example in GRACAT [22] that is software for grounding and collision risk analysis. A fault tree is a logical diagram. It determines the probability of hazard using Boolean logic to combine a series of lower-level failures such as navigator asleep and radar failure. [12][22]

The causation factor depends on several functions related to traffic perception, communication and avoidance actions. It also depends on external factors such as the vessel types involved in the potential collision situation, weather conditions, etc. To have accurate accident probabilities, the used causation factor should reflect the specific characteristics of the studied area and the properties of the ship groups in question. In this document, it is only possible to use a generic $P_c$. Some causation factors used in the literature are presented below in Table 1. When comparing $P_c$s, it has to be kept in mind that different studies evaluate differently the number of collision candidates. It means that one has to be very careful when planning to use a causation probability that has been used in another study.

In the calculations of this paper, $P_c$ is taken from literature and it does not take into account the specific characteristics of the studied area. $1.3 \cdot 10^{-4}$ is used as the causation factor for crossing ships as it is used a lot recently with Pedersen’s collision model and it does not require for example the estimation visibility conditions that is out of the scope of this work. Hänninen and Kujala are going to publish a paper about causation factor in the Gulf of Finland [25]. Their results will make the estimates of collision probabilities more precise.
Table 1: Estimates of causation probability for crossing ships.

<table>
<thead>
<tr>
<th>Value of $P_c$</th>
<th>References that use the value</th>
<th>Remarks</th>
<th>Sea area</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.11 \cdot 10^{-4}$</td>
<td>[15] (1974)</td>
<td>without Traffic Separation Scheme (TSS)</td>
<td>Dover Straits</td>
</tr>
<tr>
<td>$9.5 \cdot 10^{-5}$</td>
<td>[15] (1974)</td>
<td>with TSS</td>
<td>Dover Straits</td>
</tr>
<tr>
<td>$1.2 \cdot 10^{-4}$</td>
<td>[23] (1984)</td>
<td></td>
<td>Japan</td>
</tr>
<tr>
<td>$8.48 \cdot 10^{-5}$</td>
<td>[16] (2000)</td>
<td>in good visibility</td>
<td>North Sea</td>
</tr>
<tr>
<td>$6.83 \cdot 10^{-5}$</td>
<td>[16] (2000)</td>
<td>in good visibility within VTS zone</td>
<td>North Sea</td>
</tr>
<tr>
<td>$5.8 \cdot 10^{-4}$</td>
<td>[16] (2000)</td>
<td>in poor visibility</td>
<td>North Sea</td>
</tr>
<tr>
<td>$4.64 \cdot 10^{-4}$</td>
<td>[16] (2000)</td>
<td>in poor visibility within VTS zone</td>
<td>North Sea</td>
</tr>
<tr>
<td>$5.10 \cdot 10^{-4} - 6.00 \cdot 10^{-4}$</td>
<td>[6] (2002)</td>
<td>with mandatory reporting system, VTS and AIS; at least one of the colliding vessels is a tanker</td>
<td>Gulf of Finland</td>
</tr>
</tbody>
</table>
3 Collision Probability between Helsinki and Tallinn

In this Chapter, the calculations of the collision probability in the crossing area between Helsinki and Tallinn are presented. The studies are based on Automatic Identification System (AIS) data that is presented in Section 3.1. The methods the author uses in the analysis are defined in the Section 3.2. The estimates for collision probability in July 2006 are presented in Section 3.3 and the following Section 3.4 contains a simple sensitivity analysis of the results. Collision probability of March 2006 is presented in Section 3.5. Results are validated and commented in the following Section 3.6. Finally, collision probability for July 2015 is estimated in Section 3.7.

3.1 AIS Data

Automatic Identification System (AIS) provides a means for ships to electronically exchange information with each other and with Vessel Traffic Services (VTS). The latter allows authorities to observe maritime traffic and to inform vessels for example about weather conditions. AIS operates primarily on two dedicated radio channels but it is capable of being switched to alternate channels. AIS data includes static, dynamic and voyage-related information (see Table 2). Static information is entered on installation of the system and normally need not to be changed afterwards. Dynamic information is automatically got from the ship sensors connected to AIS and only ‘Navigational status’ needs to be manually changed. Moreover, voyage-related information is manually entered and updated. In addition, short safety-related messages may be sent via AIS. [9][26]

AIS data is stored that it makes possible to analyse sea traffic afterwards. Based on the data, it is possible to exactly define when and where each ship has moved and to formulate an image of the traffic afterwards. In this paper, AIS data is used to get traffic distributions at wanted waterways. The exact distribution makes it possible to calculate e.g. ship-ship collision risks. By the end of 2004, AIS had to be integrated to [27]

- all ships of 300 gross tonnage and upwards engaged on international voyages
- cargo ships of 500 gross tonnage and upwards not engaged on international voyages
- all passenger ships irrespective of size
Though, there are some exceptions. Some vessel types, for example warships and naval auxiliaries, do not have to carry AIS. It is good to notice that only ships having AIS installed in 2006 are included in the analysis in this paper. [27]

Table 2: Different types of AIS information.

<table>
<thead>
<tr>
<th>Static information</th>
<th>Dynamic information</th>
<th>Voyage-related information</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMSI (Maritime Mobile Service Identity)</td>
<td>Position of the ship with accuracy indication and integrity status</td>
<td>Draught of the ship</td>
</tr>
<tr>
<td>Call sign and name</td>
<td>Position Time stamp in Coordinated Universal Time</td>
<td>Hazardous cargo (type)</td>
</tr>
<tr>
<td>IMO number</td>
<td>Course over ground (COG)</td>
<td>Destination and Estimated Time of Arrival (ETA)</td>
</tr>
<tr>
<td>Length and beam</td>
<td>Speed over ground (SOG)</td>
<td>Route plan (waypoints)</td>
</tr>
<tr>
<td>Type of ship</td>
<td>Heading</td>
<td></td>
</tr>
<tr>
<td>Location of position-fixing antenna</td>
<td>Navigational status (i.e. underway by engines or at anchor)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rate of turn (ROT)</td>
<td></td>
</tr>
</tbody>
</table>

Ship Laboratory of Helsinki University of Technology has a database of two months of AIS data recorded in March and July 2006. That data has been the starting point for the analysis done in this work. Initially, March was chosen as an example month because the sea is widely frozen at that time of the year. On the other hand, July represents the marine traffic in summer. Thus, the impact of summer and winter on maritime traffic can be observed from the given data.

Figure 3 illustrates an example of the vessel traffic in the Gulf of Finland. The waterway from the entrance to the Gulf of Finland to eastern part of the Gulf of Finland is called the main route in this paper. Main part of the traffic is directed from or to the Gulf of Finland. Some ships do still operate only in the gulf, for example passenger ships and high speed crafts between Helsinki and Tallinn.
Used AIS data does not contain complete information. Ship observations without MMSI number, latitude or longitude were not stored in the database. Therefore, the calculated collision risks are smaller than the actual risks. In addition, all fields of the made observations are not fulfilled. This means that the length, speed or course over ground of the ship might be missing from AIS message. More estimation of the accuracy of used AIS data is found in reference [28].

As earlier mentioned, small vessels do not have to carry AIS but they certainly raise the risks of collision and grounding. A large number of recreational boats and fishing ships navigate in the Gulf of Finland. Especially in summer time, there are many pleasure boats crossing the gulf between Helsinki and Tallinn [5]. They are not taken into account in the author’s calculations because they do not carry AIS. Yet, these boats raise the already high risk of collision in the area.

3.2 Methods Used in the Analysis

To calculate accident risk, ships are grouped in five categories: passenger ships, cargo vessels, tankers, high speed crafts (HSCs) and other ships. Each category is divided into four groups based on size: length less than 100 metres, length at least 100 but less than 200 metres, length at least 200 m and length unknown. For the length unknown group, the average values of length and width of the whole ship type category are used. The above described groups are formulated in both directions of each lane. The considered crossing area is wide and ships do not navigate strictly along the centre of the waterway. Every vessel chooses its route independently. Therefore the angle between crossing ships varies at the crossing point. Average angle of arrival of each ship group from each
approach direction is calculated and used in the analysis. Crossing angles are calculated from Course Over Ground-field of AIS data.

### 3.3 Collision Probability in July 2006

The region of the crossing point between Helsinki and Tallinn is marked in the Figure 4. Information about ship movements in the region can be seen in Table 3 and Table 4. In this specific area, mainly fast ferries (50 %) and passenger ships (45 %) navigating between Helsinki and Tallinn were crossing mainly cargo vessels (71 %) and tankers (19 %) heading to and from more eastern Gulf of Finland. No high speed crafts navigated eastbound or westbound. Longest crude oil tankers in the area were 265 m long. In total, there were 2122 ships navigating northbound or southbound and 2303 vessels crossing them along the main route in July 2006. The velocity of fast ferries is over 30 knots that increases collision probability as there is less time to avoid a collision after a critical situation. East- and westbound traffic took place in a wide area so there was not just one clearly limited crossing area. Some ships, that crossed the main route in this area, were heading to Turku. The average angle between considered waterways was 56 degrees. The angle between ships navigating to different directions varied a lot. One reason for the large variety of crossing angles is that e.g. all northbound ships were not heading to Helsinki. Some ships were moving towards more western ports of Finland. The considered crossing is located in the middle of the Gulf and there is plenty of space to choose one’s route. The situation is of course more complex if more than two vessels approach the crossing area at the same time. Avoiding other ships may partly explain also the large variety of crossing angles.

Traffic in the crossing area in July 2006 is showed in Table 3 and Table 4. Ships were divided into groups based on type and size as described in Chapter 3.2. The model of Chapter 2.4.1 gives 61 collision candidates at this crossing per month. In 14 of the collision candidates at least one of vessels being on a collision course is a tanker. It would make about 730 collision candidates in a year of which about 160 includes at least one tanker if all months were similar to July. The model estimates the probability of a collision to be 0.095 per year in the considered collision area. It means that a collision would take place once in every 11 years. Once in 47 years a tanker would be involved in a collision. The values are calculated by multiplying numbers of collision candidates by causation factor $1.3 \times 10^{-4}$ (see Chapter 2.6).
Figure 4: Crossing area between Helsinki and Tallinn.

Table 3: Ships navigating northbound or southbound in July 2006.

<table>
<thead>
<tr>
<th></th>
<th>Number of vessels</th>
<th>Average velocity (knots)</th>
<th>Average length (m)</th>
<th>Average width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger ships</td>
<td>959</td>
<td>24.43</td>
<td>104.13</td>
<td>17.48</td>
</tr>
<tr>
<td>Cargo ships</td>
<td>80</td>
<td>13.03</td>
<td>115.98</td>
<td>17.21</td>
</tr>
<tr>
<td>Tankers</td>
<td>17</td>
<td>13.12</td>
<td>145.06</td>
<td>22.82</td>
</tr>
<tr>
<td>High speed crafts</td>
<td>1056</td>
<td>32.73</td>
<td>88.61</td>
<td>17.85</td>
</tr>
<tr>
<td>Other ships</td>
<td>10</td>
<td>9.4</td>
<td>98.2</td>
<td>14.4</td>
</tr>
</tbody>
</table>

Table 4: Ships navigating eastbound or westbound in July 2006.

<table>
<thead>
<tr>
<th></th>
<th>Number of vessels</th>
<th>Average velocity (knots)</th>
<th>Average length (m)</th>
<th>Average width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger ships</td>
<td>131</td>
<td>16.54</td>
<td>191.70</td>
<td>26.77</td>
</tr>
<tr>
<td>Cargo ships</td>
<td>1635</td>
<td>13.31</td>
<td>123.81</td>
<td>18.08</td>
</tr>
<tr>
<td>Tankers</td>
<td>445</td>
<td>14.05</td>
<td>165.03</td>
<td>26.63</td>
</tr>
<tr>
<td>High speed crafts</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other ships</td>
<td>92</td>
<td>11.64</td>
<td>107.22</td>
<td>17.16</td>
</tr>
</tbody>
</table>
3.4 Sensitivity Analysis of Traffic in July 2006

This simple sensitivity analysis of crossing between Helsinki and Tallinn is made with summer traffic presented in Table 3 and Table 4. If all ships were 10 m longer, the number of collision candidates would rise from 61 to 65. If all ships were 5 m wider, there would be 63 collision candidates. As seen, collision probability would increase if dimensions of ships grew. If the angle between waterways were 10 degrees closer to the right-angle, the number of collision candidates would drop to 59. The three preceding changes would have an impact of about the same magnitude.

If all traffic in the crossing was multiplied by 1.5, the amount of collision candidates would be 137. Traffic volume has an enormous impact on the collision probability which would rise more than be multiplied by the same factor than the amount of traffic. The effect of traffic growth is also seen in Section 3.7 where collision probability is calculated with estimated traffic of the year 2015. Increasing ship traffic is a fact in the Gulf of Finland and so the amount of accidents is also expected to grow.

If the velocity of vessels increased 5 knots, the model would give only 45 collision candidates. Normally, the amount of collisions would be expected to grow if velocity increased. However, the model reflects the geometrical probability of a collision. It is obvious that a ship passes the crossing area faster if its speed is higher and therefore it has less time to collide with other ships. Yet, vessels navigating faster have also less time to make aversive manoeuvres if they are about to collide. The probability of being able to avoid an accident is modelled in causation factor. Thus, the differences in velocity of ship groups should have an influence on their $P_c$'s. A generic causation probability is used in this paper which denotes that velocity of a ship group does not affect the value of $P_c$ of the group. This is one of the reasons that make the results less precise. The whole model is very sensitive to the value of $P_c$ as the number of collision candidates is multiplied by it.

To conclude this simple sensitivity analysis, the author argues that the model is the most sensitive to causation probability and to traffic volume. In addition, velocity has also a great role because causation factor is not separately defined to different ship groups in this paper. Instead, relatively small changes in crossing angle or the magnitude of ships do not change the result a lot.
3.5 Collision Probability in March 2006

The crossing area between Helsinki and Tallinn was also studied during winter time. The example period is 21 days in March 2006. Total amount of ships navigating between Helsinki and Tallinn (see Table 5) was 444 of which 72 % were passenger ships and 20 % were cargo vessels. In winter, there are no high speed crafts navigating between Helsinki and Tallinn which significantly decreases the average speed of ships in the studied area. In total, 1414 vessels (see Table 6) were moving eastbound or westbound. 65 % of them were cargo ships, 20 % were tankers and 8 % were passenger ships.

The model presented in Section 2.4.1 gives 17 collision candidates in 21 days. In a year, it would make 300 collision candidates which is only 41 % of the number of yearly collision candidates calculated with data of July in Section 3.3. At least one tanker is involved in 78 of the yearly collision candidates. The difference reflects the smaller number of ship movements in the area in winter. The amount of ships that go through the considered area in March is only 62 % of the amount in July. The preceding calculation does not pay attention to weather conditions. In March, the whole Gulf of Finland may be covered with ice. The studied ice season 2005-2006 was average. The largest ice cover was reached on March 16 when the whole Gulf of Finland was covered with ice. [29] Average ice season might mean that the amount of traffic and the types and sizes of ships that navigated in the Gulf of Finland in March 2006 represented average winter traffic from the analysis point of view. The studied winter could then be well used to estimate average collision probabilities in the long term.

Table 5: Ships navigating southbound of northbound during 21 days in March 2006.

<table>
<thead>
<tr>
<th></th>
<th>Number of vessels</th>
<th>Average velocity (knots)</th>
<th>Average length (m)</th>
<th>Average width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger ships</td>
<td>318</td>
<td>16.27</td>
<td>147.97</td>
<td>24.33</td>
</tr>
<tr>
<td>Cargo ships</td>
<td>91</td>
<td>9.66</td>
<td>119.71</td>
<td>17.80</td>
</tr>
<tr>
<td>Tankers</td>
<td>19</td>
<td>9.58</td>
<td>140.74</td>
<td>21.58</td>
</tr>
<tr>
<td>High speed crafts</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other ships</td>
<td>16</td>
<td>10.93</td>
<td>98.88</td>
<td>19.56</td>
</tr>
</tbody>
</table>
Table 6: Vessels navigating eastbound or westbound during 21 days in March 2006.

<table>
<thead>
<tr>
<th></th>
<th>Number of vessels</th>
<th>Average velocity (knots)</th>
<th>Average length (m)</th>
<th>Average width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger ships</td>
<td>109</td>
<td>18.02</td>
<td>183.52</td>
<td>29.07</td>
</tr>
<tr>
<td>Cargo ships</td>
<td>914</td>
<td>12.58</td>
<td>130.96</td>
<td>19.15</td>
</tr>
<tr>
<td>Tankers</td>
<td>282</td>
<td>11.81</td>
<td>163.47</td>
<td>25.83</td>
</tr>
<tr>
<td>High speed crafts</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other ships</td>
<td>109</td>
<td>11.77</td>
<td>116.49</td>
<td>22.75</td>
</tr>
</tbody>
</table>

In winter time, navigable parts of channels are narrower than in summer which means that there is less space to avoid other vessels. To make the situation even worse, night is much longer in winter than in summer and other ships are more difficult to perceive in the darkness. All mentioned factors should be covered when winter time accident probabilities are modelled. They can be taken into account in the estimation of decent causation probability. A specific $P_c$ for winter circumstances is not estimated in this paper. When the generic causation factor for crossing ships, $1.3 \cdot 10^{-4}$, is used, the probability of a collision per year is 0.038. It results in a collision in 26 years of which a tanker is involved every 98 years.

3.6 Validation and Commentary of Results

According to the report of Helsinki Commission [30], 1-2 collision accidents occurred in the studied area during 2000-2006. One accident is certainly in the analysed area but the other one seems to be at the edge of it and might be even outside the area. It seems that the used model gives a bit smaller probabilities (see Table 7) than what have realised in the past. However, traffic is continuously increasing which means that the model would have given even smaller collision probabilities e.g. for the traffic of year 2000. A period of seven years is also too short to figure out if the number of accidents during that time was just a coincidence or near to long time average. Though, it is the best available number to compare with the calculated probabilities. The navigational conditions have also changed after 2000. GOFREP (Gulf of Finland Reporting system) was introduced in 2004 [9]. It is a joint maritime traffic control system that is maintained by Finland, Estonia and Russia in cooperation. AIS was not yet in use in 2000. These systems have increased marine security in the studied area.
Table 7: Results for March and July 2006.

<table>
<thead>
<tr>
<th></th>
<th>In March 2006</th>
<th>In July 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision probability per year</td>
<td>0.038</td>
<td>0.095</td>
</tr>
<tr>
<td>Collision candidates per month</td>
<td>25</td>
<td>61</td>
</tr>
<tr>
<td>Of which a tanker involved</td>
<td>6.6</td>
<td>14</td>
</tr>
<tr>
<td>Estimated interval between collisions (years)</td>
<td>26</td>
<td>11</td>
</tr>
<tr>
<td>Estimated interval between collisions in which at least one tanker involved (years)</td>
<td>98</td>
<td>47</td>
</tr>
</tbody>
</table>

It is essential that ship traffic is not similar in the studied area around the year. Based on earlier discussions, it is visible that winter and summer traffic significantly differ from each other (see Table 7). The seasonal differences of traffic have to be taken into account when calculating the probability of collisions in a year. This has not been possible during the analysis reported in this paper. Still, the results presented in previous chapters seem indicative.

Collision probabilities in the studied crossing area are presented in Table 7. As can be seen, probabilities differ significantly. However, geometrical collision probabilities of both months are multiplied by same causation factor although conditions in winter are remarkably more challenging than in summer. The actual collision probability of the studied area could be defined by weighted average of summer and winter probabilities. It should also be considered if a new scenario is also created for example about autumn traffic.

One reason for imprecision is that it is often impossible to say exactly where a shipping lane converges to another waterway. Especially in open sea, a ship may continue its voyage long way parallel to the actual waterway where most of the vessels navigate (see e.g. Figure 4). This kind of action cannot be taken into account in the used model. Of course, the more distinctive crossing and merging areas have the biggest impact on the collision probability of the whole Gulf of Finland.

The used model for crossings does not pay attention to distribution of traffic during day and night. The actual traffic differs according the time of day. For example, fast ferries operate mostly at
daytime. A solution to that problem could be that traffic during the day and the night would be studied separately. In practise, different causation factors for day and night could be used.

3.7 Consideration of the Future

The aim of this Chapter is to define the change of collision risk in the studied area between 2006 and 2015. First, an estimate of marine traffic between Helsinki and Tallinn is presented for the year 2015. Then, the probability of collision in 2015 is defined in.

It is estimated that maritime traffic will increase a lot in the Gulf of Finland in the near future. The Finnish Environment Institute estimates that total oil transportation will increase up to 250 million tonnes in 2015 in the Gulf of Finland. In 2006, the amount of transported oil was just below 140 million tonnes. The increasing oil transports are coming from Russia where new oil terminals are under construction. The estimated amount of transported oil for 2015 is 1.8 times the amount of 2006 and it signifies a remarkable growth of risks compared to the calculations presented earlier in this paper. Average size of oil tankers is growing which means that the amount of oil tankers in the Gulf of Finland is not increasing in exactly same proportions as the amount of transported oil. Yet, it is difficult to estimate the distribution of tanker size in 2015. Therefore in the following calculations, only the increase of the number of tankers is taken into consideration. The amount of oil transported to and from Finland and western Estonia is not predicted to grow. Therefore for the calculations of risk level in 2015, the number of tankers navigating along the main route of Gulf of Finland is estimated to be twice the amount of tankers in 2006. It signifies that tanker traffic would on average grow by 8 % annually. [4]

The volume of cargo transported via the Gulf of Finland is also growing. In the following calculations, a coefficient of 1.5 is used for the number of cargo vessels heading to and from Russia in 2015 compared to 2006. The used coefficient would mean 4.6 % annual growth. However, passenger traffic is not expected to grow significantly before 2015.

If traffic volume developed as assessed above, estimated time intervals between collisions would correspond the values of Table 8. The calculations are made with summer traffic so the results do not give a good picture of the collision risk during a whole year. Increase of collision candidates is significant. Even though maritime security has been improved in 21st century in the Gulf of Finland, more accidents can be expected due to continuously increasing traffic flows. The amount of traffic is the most influencing parameter of the crossing model as shown in Chapter 3.4. According to
calculations with estimated traffic in 2015, collision probability rises 56 \%. The probability of a collision in which at least one tanker is involved rises 98 \%. These numbers demonstrate the enormous growth of oil accident risk in the Gulf of Finland due to the increase in traffic in the near future. It is important to remember that not only oil tankers carry oil but also large cargo vessels carry a large amount of bunker oil which is alike damaging to the nature [31]. Thus, the number of all accidents must be minimized to minimize the amount of oil spilled into the sea.

Table 8: Comparison of the estimated time intervals between collisions in 2006 and 2015.

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated time interval of collisions (years)</td>
<td>11</td>
<td>6.8</td>
</tr>
<tr>
<td>Estimated time interval of at least one tanker involved in collision (years)</td>
<td>47</td>
<td>24</td>
</tr>
</tbody>
</table>

It should be noticed that the amounts of collision candidates for the year 2015 are calculated by multiplying the traffic of the year 2006 as explained above. Some ship groups contain only few vessels. Their average size and crossing angles are not likely to give a decent picture of the qualities of the group in general. If traffic grows as assumed, the results most probably give a rather good estimate of the increase in the collision risk level between 2006 and 2015.

4 Discussion and Conclusions

The applied ship-ship collision model covers only a crossing situation of two vessels. In particular, in heavily trafficked locations, three or even more ships may approach the area at the same time. In this kind of situation, a collision is more difficult to avoid when actions of several other vessels need to be observed.

The applied collision probability model cannot handle traffic that is not evenly distributed around the clock which results in the situation that sometimes there are more and sometimes less traffic than the model would expect. For example, passenger traffic between Helsinki and Tallinn is more
active during the day than at night time. This changes risk level from the estimate given by the model. The mentioned problem could be avoided by simulation that utilizes timetables of ferries.

The analysis done in this paper is based on the traffic of only two months period, July and March 2006. Though, the amount of traffic during a month is partially random which makes the results less accurate. On the other hand, a part of the traffic is regular, e.g. many passenger ships operate on the same schedule for several months which decreases the randomness of the traffic. In some of the studied waterways, there were much more traffic to one direction than to another. Presumably it is most often due to randomness and not the average situation. Still, it affects the results presented in this paper. The amount of traffic is largely dependent on season as seen when the traffic of July and March were compared with each other.

One of the biggest error sources in this paper is the causation factor. In this study, the author uses a very general estimate of it although the Gulf of Finland is not a general area for navigators due to its islands, shallows, darkness and ice conditions in winter. Probably a bigger causation probability should be used as proposed in reference [6]. Specific causation factors that are estimated especially for different ship classes, locations and weather conditions (including winter) are needed to evaluate more accurate probabilities of collisions and groundings in the Gulf of Finland. One paper concentrating on that topic is to appear [25].

This paper presented criteria for evaluating a collision probability model. Based on the evaluation, Pedersen’s model was selected and applied to estimate collision risk in the crossing area between Helsinki and Tallinn. Also an estimate of collision probability for the year 2015 was made. If traffic increases as estimated in the literature, the model predicts the collision probability to raise 56% between Helsinki and Tallinn from 2006 to 2015. The probability of a collision, in which there is at least one tanker involved, raises 98%. The results presented in this paper pave the way for analyzing more profoundly accident risks in the Gulf of Finland. The risks should be estimated equally in the whole gulf as if oil is spilled into the sea, it spreads to a wide area. Thus, the exact location of a collision or grounding does not play so important role.
References


[27] International Maritime Organization. IMO www pages (online) [cited on 28.1.2009]. Available at: <URL: http://www.imo.org>

