IWRAP MK II

WORKING DOCUMENT

BASIC MODELLING PRINCIPLES FOR PREDICTION OF COLLISION AND GROUNDING FREQUENCIES:

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1. BACKGROUND

The objective of the present report is to describe the theoretical background for the collision and grounding frequency analysis that forms the basis of the IWRAP MK II program. The IWRAP MK II constitutes a reduced version of the collision and grounding analysis program, The BaSSy ToolBox (GRISK) that is being developed under the BaSSy-project. The BaSSy project is a joint research project between Technical University of Denmark, GateHouse (Denmark), SSPA (Sweden), and VTT (Finland), which is funded in part by The Danish Maritime Foundation and Det Nordiske Ministerråd. The objective of the present report is to describe the theoretical foundation for the collision and grounding frequency analysis so that the interested user of IWRAP MK II may understand the fundament behind the program. It is assumed that the reader assumes a level of mathematical and probabilistic skills to gain full benefit of the report.

2. INTRODUCTION

To quantify the risks involved with vessel traffic in specified geographical areas, rational criteria for prediction and evaluation of grounding and collision accidents have to be developed. This implies that probabilities as well as the inherent consequences have to be analysed and assessed.

During the period from 1998 to 2001 state-of-the-art software for grounding and collision analysis that was developed within the ISESO project at the Technical University of Denmark. The ISESO project was conceived by the Danish Maritime Authority (Søfartsstyrelsen) in co-operation with Danish maritime industries and trades. The purpose of ISESO was to develop front-end technological maritime simulation tools for the benefit of Danish shipping, and the aim has been to contribute to maintaining and extending the Danish position within this area of commercial activity. The acronym ISESO stands for Information Technology for Increased Safety and Efficiency in Ship Design and Operation (in Danish: “Informationsteknologi i forøget Sikkerhed og Effektivitet i Skibsdesign og –Operation”), see www.iseso.org for more information.

One of the objectives of the ISESO project was to develop a software package of rational tools for streamlining and assisting in applying FSA methods. The developed computer program, GRACAT (Grounding and Collision Analysis Toolbox) facilitates these types of analyses and further provides rational tools for evaluating and comparing the grounding and collision risk for the analysed alternatives.

The software calculates the probability of collision or grounding for a vessel operating on a specified route. Given that a collision or grounding event has taken place the spatial distribution of the damages to the hull may further be calculated. Results are presented in terms of probability distributions for indentation depth, length and height of the damage and for their location. A special case of a probabilistic analysis is a purely deterministic analysis, which also may be performed within GRACAT. Results for accident frequency and damage have been compared to registered data and good agreement was found in all cases.

The procedures developed during the development of GRACAT constitutes an essential part of the BaSSy project and thus also of the program with the working title “IWRAP MK II”. Therefore, the theoretical foundation given in this document is to large extent routed in the basis established during the ISESO-project. The document not only defines the theoretical background for the collision and grounding analysis, but it also summarises and discusses the background for the so-called *causation probability*.

The document outlines a method for evaluating the collision and grounding frequency of vessels operating on a specified route. To identify the frequency of experiencing any collision or grounding in a given area involves first a specification of the routes and the associated traffic on the routes. Subsequently, the collision and ground frequency may be obtained by looping over all vessels operating on the route. The BaSSy program will contain tools for extracting the traffic distribution and traffic density functions from AIS data. These tools *are not part of* the IWRAP MK II program[1]. Given that a collision or grounding has taken place the spatial distribution of the damages may further be calculated. Results of such analysis may in the BaSSy program be presented in terms of probability distributions, for indentation depth, length and height of the holes and for their location. Knowing the structural damage the resulting consequences in terms of bunker oil outflow and cargo outflow may subsequently be calculated. In future more consequence models will be implemented in the BaSSy program. The IWRAP MK II program *does not* include the consequence analysis package.

One of the benefits of the formulated procedure is that it allows comparisons of various navigational routes by assessing the relative frequencies of collisions. Under the ISESO project the derived procedure was applied to different Ro-Ro passenger vessel routes (Great Belt, Dover-Calais, Turku-Stockholm). The results of the analyses were compared to registered data and good agreement was found in all cases. This constituted the validation of the software for frequency and damage distribution estimation by the GRACAT program.

The applied model for calculating the frequency of grounding or collision accident involves the use of a so-called causation probability that is multiplied onto a theoretically obtained number of grounding or collision candidates. The causation factor models the probability of the officer on the watch not reacting in time given that he is on collision course with another vessel (or alternatively on grounding course). The numerical value of the causation probability is not a unified value but often varies for different geographical locations. The applied value of the causation probability is therefore typically adjusted by a calibration to registered data.

On the basis of a literature search the present document summarises some of the causation probabilities that have been applied in different studies. The document also identifies some of the factors that are of importance when assessing the causation probability. Moreover, a Bayesian Network model for ship-ship collision is formulated for an analytical estimation of the causation probability. The obtained result agrees well with that obtained from statistical analyses of data.

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[1] Contact GateHouse (pch@gatehouse.dk) for information on how to get access to these toolboxes.

3. PROBABILISTIC COLLISION AND GROUNDING ANALYSIS

Already in 1974 Fujii et al. [5] and also MacDuff [21] initiated more systematic and risk based approaches for grounding and collision analysis. MacDuff studied grounding and collision accidents in the Dover Strait and calculated a theoretical probability of the both the grounding and the collision event. This probability was calculated by assuming all vessels to be randomly distributed in the navigational channel. MacDuff denoted the thus obtained probability the *geometric probability*, since this probability was entirely based on a geometric distribution of ships that were "navigating blind". By comparing to the observed number of grounding and collision it was found that the geometric probability predicted too many events and a correction factor P_c was introduced to account for the difference. The correction factor was denoted the *causation probability* and it models the vessels and the officer of the watch's ability to perform evasive manoeuvres in the event of potential critical situation. In the study MacDuff found that the causation probability was 10^{-4} for collisions in crossings, and $5{\cdot}10^{-4}$ for head-on collisions.

Using an approach similar to MacDuff [21], Fujii *et al.* [5] introduced a *probability of mis-manoeuvres* on the basis of grounding statistics for several Japanese straits. For the considered straits the probability was found to be in the range from $0.6{\cdot}10^{-4}$ to $1{\cdot}10^{-3}$.

Common for both studies is that they assume the vessels to be randomly distributed over the considered waterway. It is in this respect very important to note that the causation probability obtained in the two studies is dependent on this (rather crude) assumption. Hence, in case a more realistic distribution of the ship traffic over the waterway is assumed, then the causation probability will change accordingly.

The advantage of the approach suggested by Fujii *et al.* [5] and by MacDuff [21] is its simplicity and the related robustness. This is, however, also a drawback since the defined causation probabilities cannot be directly used if more detailed models are applied for the geometrical distribution of the vessels. Nonetheless, the two studies provide a proper framework for the general risk model for evaluating the frequency of grounding and collision accidents, and they provide valuable guidelines for the order of magnitude of the causation probability.

3.1 Risk models

Today most risk models for estimating the grounding or collision frequency are routed in the approach defined by Fujii *et al.* [5] and by MacDuff [21]. That is, the potential number of ship grounding or ship-ship collisions is first determined as if no aversive manoeuvres are made. This potential number of ship accidents is based on 1) an assumed or pre-specified geometric distribution of the ship traffic over the waterway and 2) on the assumption that the vessels are navigating blindly as these are operating at the considered waterway. The thus obtained number of potential accident candidates (often called the *geometric number of collision candidates*) is then multiplied by a specified causation probability to find the actual number of accidents. The causation probability, which acts as *a thinning probability* on the accident candidates, is estimated conditional on the defined "blind navigation".

The above-described approach is often termed the *scenario approach*, since it utilises certain accident scenarios and statistics for the cause of these scenarios. The statistics mainly come into the analysis through the defined value of the causation probability. This implies that the scenario approach as applied today – in principle – represents all types of accident scenarios, provided that they are included in the statistical basis.

An alternative risk analytical approach, the *synthesis approach*, see Gluver and Olsen [12], base the risk of grounding or collision on a set of scenarios where specific error situations or conditions are assumed to occur or exist in the vessel prior to or during the considered critical situation. Such an approach, however, requires that all significant accident scenarios are identified and analysed. Consequently, this also implies that the causation probability must be defined conditional on considered accident scenario. It therefore follows that the advantage of introducing the *synthesis approach* is that alternate risk-mitigating aspects more easily may be both identified and quantified. Examples of different accident scenarios could be rudder stuck, power failure, navigational error, etc. Each of these scenarios may be further sub-divided to describe the scenario in more details e.g., in what position the rudder is stuck and what other equipment is available to mitigate the problem.

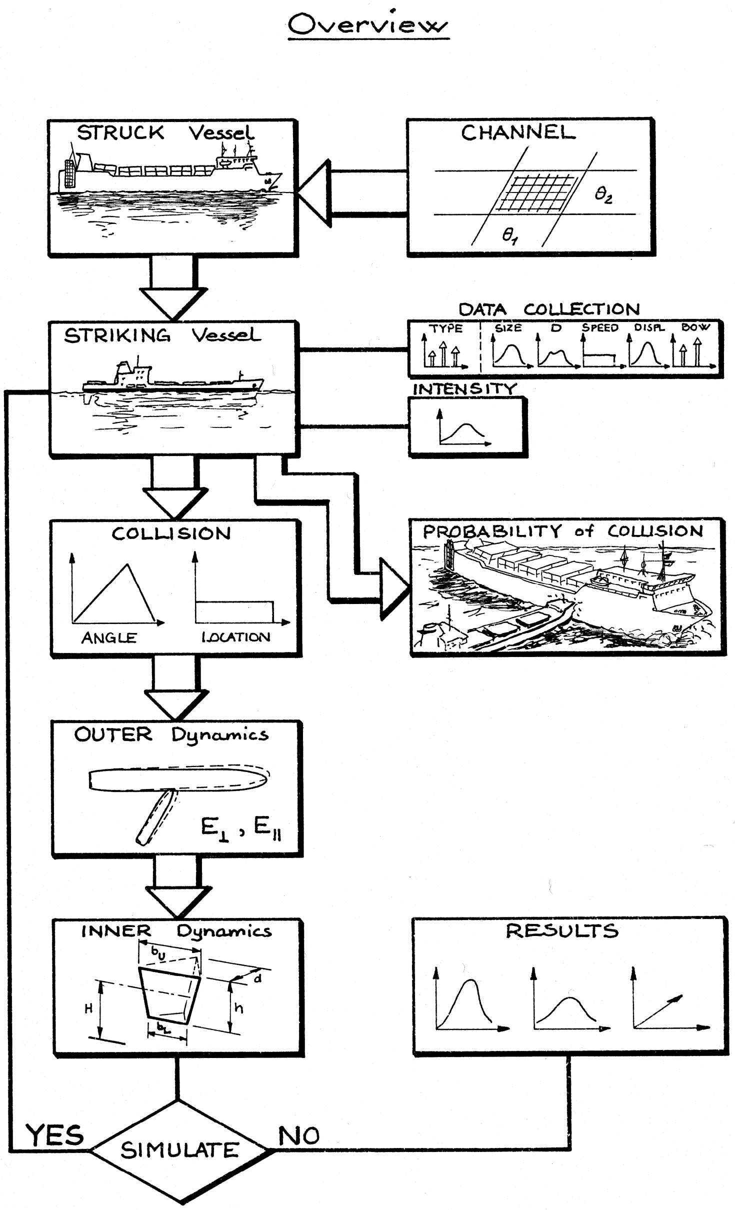


Figure 1 Overall procedure for probabilistic prediction and spatial distribution of collision damages.

In the present work the scenario approach is applied and the procedure is schematically illustrated in Figure 1 for the collision analysis. A grounding analysis follows the same conceptual outline. Basically the procedure is as follows: First the relevant navigational area is described. This involves description of the traffic composition along all navigational routes and descriptions of all grounds in the vicinity of the route. Next the considered vessel (termed struck vessel in Figure 1) is defined to be operating on a specified route in the defined navigational area. All potential other vessels (striking vessel in Figure 1) or grounds is then identified and the probability of grounding and collision is calculated. Subsequently, the identified ground or striking vessel may further be used for calculating damage statistics. The ensuing consequence analysis (in terms of time to capsize, oil outflow, etc.) of the identified damages is not shown in the figure, but statistics for this may similarly be obtained.

Although the procedure described above resembles the scenario approach the alternative synthesis approach may also be covered by careful application of the causation factors. Structured methods for this will be illustrated later by the application of Bayesian Networks for obtaining the causation factor.

4. PREDICTING COLLISION AND GROUNDING FREQUENCIES

The conceptual procedure for calculation of the frequency of collisions or groundings follows the conceptual principles formulated by Fujii [7]. The procedure first involves the calculation of the geometric number of collision or grounding candidates, N_G, which subsequently is multiplied by the causation factor, P_C. Hence the frequency of collisions, λ_{Col}, (or groundings, λ_{Grnd}) become,

$$\lambda_{\mathrm{Col}} = P_C \cdot N_G \tag{4.1}$$

The theoretical procedure laid out in this chapter represent the state-of-the-art framework that is applied for calculating the geometric number of collision and grounding candidates, N_G. The values of the causation factor, P_C, are typically in the range from .

A prerequisite for the analysis is that the ship traffic has been grouped into a number of different ship classes according to vessel type, size, loaded or ballasted, with or without bulbous bow etc., and that the number of vessels per time unit have been registered for each waterway. It is noted that in the analysis presented below the time unit for the definition of number of vessels is in seconds^{-1} for dimension correctness.

4.1 Frequency of collision

Collisions may coarsely be divided into two types:

- collisions along the route segment, i.e. overtaking or head-on collisions, and
- collisions when two routes crosses each other, merges, or intersects each other in a turn.

The procedure for calculation of the number of collision candidates, N_G, for the above-mentioned two types are conceptually different since the geometric number of collision candidates first type becomes dependent on the lateral traffic spread on the route whereas the second is independent of the traffic spread. This can be seen by comparing Figure 2 and Figure 3. By inspecting Figure 2 it can be seen that the probability of the path of two meeting ships will overlap depends on the spreading of the lateral position where the vessels are sailing. The larger the μ-value the smaller becomes the probability of a collision. In Figure 3 it can be seen that although the "risk area" is affected by the spread of the traffic the probability of the ships meeting each other is not.
In the following the head-on and overtaking collisions will first be treated, thereafter will the crossing collisions.

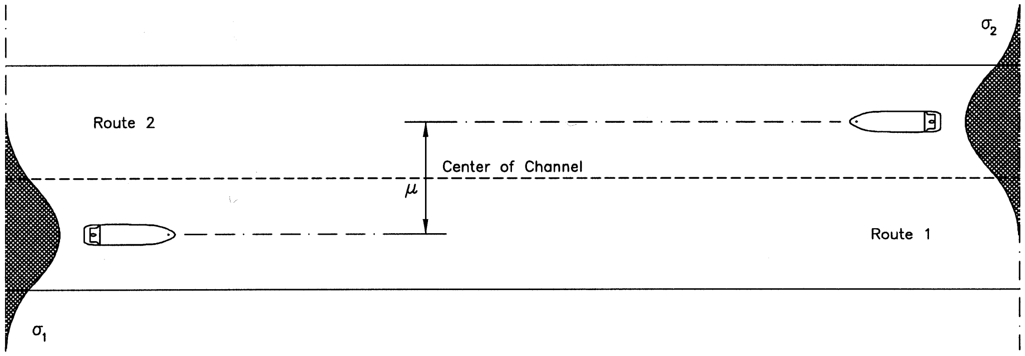


Figure 2 Definition of μ-ratio and traffic distribution.

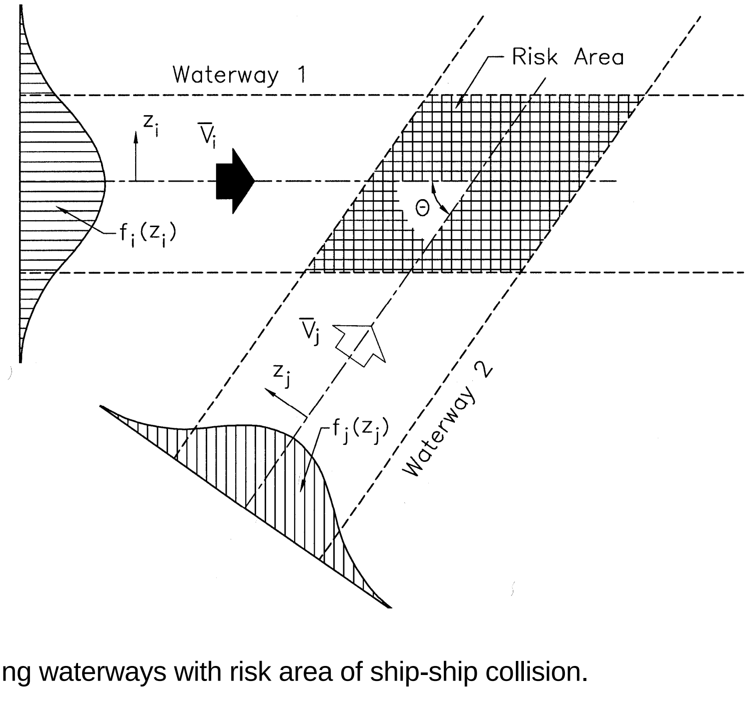


Figure 3 Crossing waterways with risk area of ship-ship collision.

4.1.1 Head-on and overtaking collisions

Collisions along the route, see Figure 2, depends of

- The length, L_W, of the segment;
- The traffic composition, i.e. the number of passages per time unit for each ship type and size, $Q_i^{(1)}$ and $Q_j^{(2)}$, in each direction, (1) and (2), and their speed, $V_i^{(1)}$ and $V_j^{(2)}$;
- The geometrical probability distribution, $f_i^{(1)}(y)$ and $f_j^{(2)}(y)$, of the lateral traffic spread on the route. The traffic spread is typically defined by a Normal distribution but may in principle be of any type. The sign convention for the traffic distribution is measured from the centre of the channel and positive towards the right side in the sailing direction.

For *head-on collisions* the number of geometric collision candidates for ships sailing along the route segment in direction (1) and (2) can be expressed as,

$$N_G^{\text{head-on}} = L_W \sum_{i,j} P_{G\,i,j}^{\text{head-on}} \frac{V_{ij}}{V_i^{(1)} V_j^{(2)}} \left(Q_i^{(1)} Q_j^{(2)} \right) \tag{4.2}$$

where $V_{ij} = V_i^{(1)} + V_j^{(2)}$ is the relative speed between the vessels and P_G defines the probability that two ships will collide in a head on meeting situation. This probability is expressed as

$$\begin{aligned}
P_{G\,i,j}^{\text{head-on}} &= P\left[y_i^{(1)} - \frac{B_i^{(1)}}{2} < -y_j^{(2)} + \frac{B_j^{(2)}}{2} \cap y_i^{(1)} + \frac{B_i^{(1)}}{2} > -y_j^{(2)} - \frac{B_j^{(2)}}{2} \right] \\
&= P\left[y_i^{(1)} + y_j^{(2)} < \frac{B_i^{(1)} + B_j^{(2)}}{2} \right] - P\left[y_i^{(1)} + y_j^{(2)} < -\frac{B_i^{(1)} + B_j^{(2)}}{2} \right] \\
&= \int_{-\infty}^{\infty} \int_{y_j = -y_i - \overline{B}}^{-y_i + \overline{B}} f_{Y_i}(y_i)\, f_{Y_j}(y_j)\, \mathrm{d}y_i\, \mathrm{d}y_j \\
&= \int_{-\infty}^{\infty} f_{Y_i}(y_i) \left[F_{Y_j}(-y_i + \overline{B}) - F_{Y_j}(-y_i - \overline{B}) \right] \mathrm{d}y_j
\end{aligned} \tag{4.3}$$

It is noted that the random variable $y_j^{(2)}$ is negative because of the positive sign convention in the sailing direction of the two vessels. In the last step it has been utilized that the two distributions are independent. It is possible to establish a closed form solution to Eq. (4.3) when the traffic distributions are normally distributed. In the general case Eq. (4.3) must in be solved by approximate procedures such as FORM/SORM or numerical integration. When $f_i^{(1)}(y)$ and $f_j^{(2)}(y)$ both follow a normal distribution with distribution parameters (μ_i, σ_i) and (μ_j, σ_j), respectively, eq. (4.3) can be written as:

$$P_{G\,i,j}^{\text{head-on}} = \Phi\left(\frac{\overline{B}_{ij} - \mu_{ij}}{\sigma_{ij}} \right) - \Phi\left(-\frac{\overline{B}_{ij} + \mu_{ij}}{\sigma_{ij}} \right) \tag{4.4}$$

In which $\Phi(x)$ is the standard normal distribution function, $\mu_{ij} = \mu_i^{(1)} + \mu_j^{(2)}$ is the mean sailing distance between the two vessels, $\sigma_{ij} = \sqrt{\left(\sigma_i^{(1)}\right)^2 + \left(\sigma_j^{(2)}\right)^2}$ is the standard deviation of the joint distribution, and $\overline{B}_{ij} = \dfrac{B_i^{(1)} + B_j^{(2)}}{2}$ is the average vessel breadth.

The frequency of head on collisions, $\lambda_{\text{Col}}^{\text{head-on}}$, is obtained by multiplying the geometric number of collisions, $N_G^{\text{head-on}}$, with the causation factor for head on collisions, $P_{\text{C}}^{\text{head-on}}$. In the DROGDEN study a causation factor of $1.3 \cdot 10^{-4}$ was applied for head-on and overtaking collisions. In the resent study “Oil and Chemical spills in Danish waters” [3] a factor of $3.0 \cdot 10^{-4}$ was proposed. Based on collision statistics in Japanese waters, Fujii *et al.* [8] has estimated that for meeting ships in parallel waterways $P_c = 4.9 \cdot 10^{-5}$.

For *overtaking collisions* the number of geometric collision candidates for ships sailing along the route segment in direction (1) is expressed by eq. (4.2) using the relative speed $V_{ij} = V_i^{(1)} - V_j^{(1)}$, $V_{ij} > 0$. If $V_{ij} < 0$ then vessel i will obviously not be able to overtake vessel j. In the practical implementation the absolute value of V_{ij} is used and struck and striking vessel are registered. The geometric probability of meeting, eq. (4.3) becomes,

$$P_{G\,i,j}^{\text{overtaking}} = P\left[y_i^{(1)} - y_j^{(1)} < \frac{B_i^{(1)} + B_j^{(1)}}{2} \right] - P\left[y_i^{(1)} - y_j^{(2)} < -\frac{B_i^{(1)} + B_j^{(1)}}{2} \right] \qquad (4.5)$$

For normally distributed variables the mean value in eq. (4.4) should be replaced by $\mu_{ij} = \mu_i^{(1)} - \mu_j^{(1)}$ to handle the overtaking situation.

4.1.2 Crossing collisions

The frequency of crossing collisions depends on the angle between the two lanes. Figure 3 shows two crossing waterways for which the ship traffic also is given. The geometric number of *crossing collisions* candidates for crossing waterways can similarly to eq. (4.2) be expressed as,

$$N_G^{\text{crossing}} = \sum_{i,j} \frac{Q_i^{(1)} Q_j^{(2)}}{V_i^{(1)} V_j^{(2)}} D_{ij} V_{ij} \frac{1}{\sin\theta} \qquad \text{for} \quad 10° < |\theta| < 170° \qquad (4.6)$$

where $V_{ij} = \sqrt{\left(V_i^{(1)}\right)^2 + \left(V_j^{(2)}\right)^2 - 2 V_i^{(1)} V_j^{(2)} \cos\theta}$ is the relative speed between the vessels and $D_{i,j}$ defines the apparent collision diameter, see Figure 4. The sinus term stems from the variable transformation when integrating over the area of the joint probability distribution, see Figure 7. Note that contrary to head-on and overtaking collisions the distribution of the traffic spread is not relevant for crossing collisions, except for the sinus term of course. It is seen that when the crossing angle goes to zero the length of the crossing (or the time of the crossing) goes to infinity and hence does the number of collisions. For practical reasons it is therefore necessary to limit the crossing angle to an interval of, say, 10 to 170 degrees.

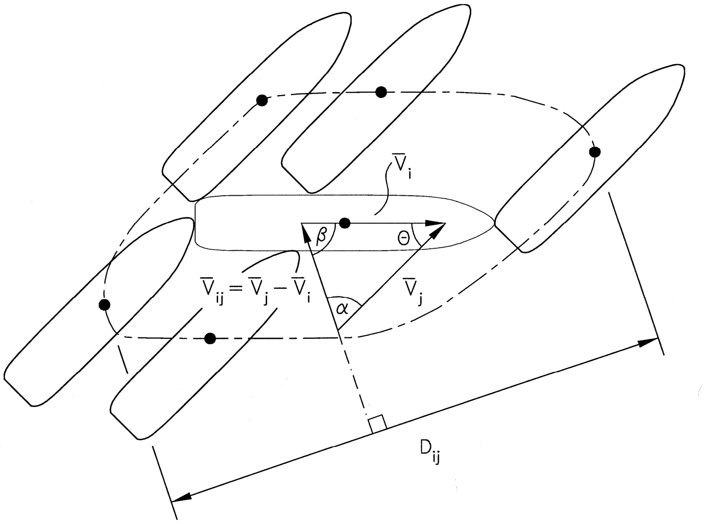


Figure 4 Definition of geometrical collision diameter D_{ij}.

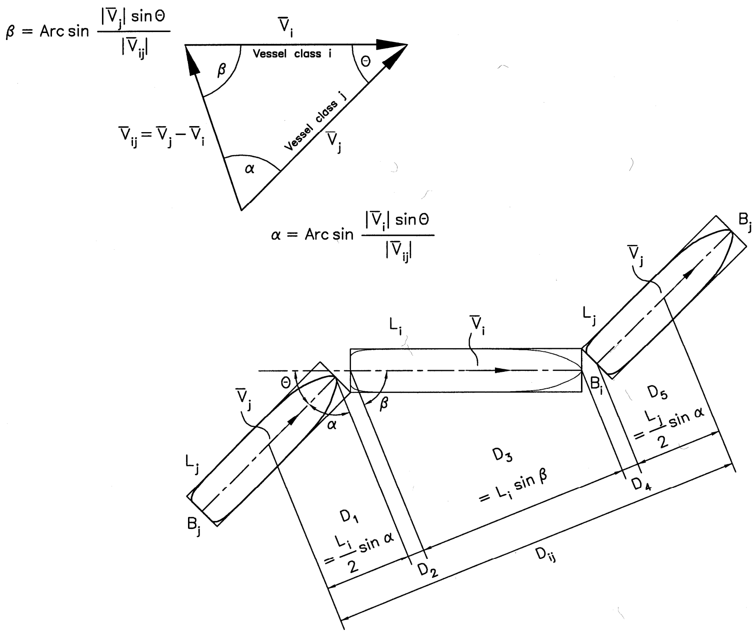


Figure 5 Calculation of the geometrical collision diameter D_{ij}.

As mentioned D_{ij} is the geometrical collision diameter illustrated in Figure 4. If it is assumed that the ships can be approximated by rectangular shapes, then it can be shown, see Figure 5, that:

$$D_{ij} = \frac{L_i^{(1)}\ V_j^{(2)}\ + L_j^{(2)}\ V_i^{(1)}}{V_{ij}} \sin\theta + B_j^{(2)} \left\{ 1 - \left(\sin\theta\ \frac{V_i^{(1)}}{V_{ij}} \right)^2 \right\}^{1/2} + B_i^{(2)} \left\{ 1 - \left(\sin\theta\ \frac{V_j^{(2)}}{V_{ij}} \right)^2 \right\}^{1/2} \tag{4.7}$$

where the relative velocity V_{ij} is determined as

$$V_{ij} = \sqrt{\left(V_i^{(1)}\right)^2 + \left(V_j^{(2)}\right)^2 - 2\,V_i^{(1)} V_j^{(2)} \cos\theta} \tag{4.8}$$

and where B_i is the width of ship i and L_i the length.

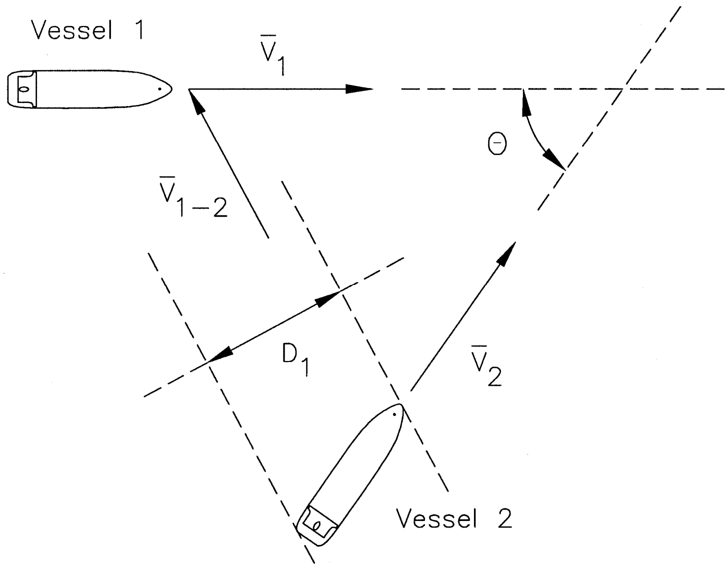


Figure 6 Illustration of the apparent diameter for vessel 1 striking vessel 2.

In the present work we are not only interested in the number of ship-ship collisions but also in the probability of the one or the other being the struck or striking vessel. To derive a simple expression for this event the apparent collision diameter is formulated, see Figure 6. The apparent collision diameter seen from vessel i, $D_i^{(1)}$, can be determined as

$$D_i^{(1)} = \frac{L_j^{(2)} V_i^{(1)} \sin\ \theta}{V_{ij}} + \frac{1}{2} B_j^{(2)} \left\{ 1 - \left(\sin\theta \frac{V_i^{(1)}}{V_{ij}} \right)^2 \right\}^{1/2} + \frac{1}{2} B_i^{(1)} \left\{ 1 - \left(\sin\theta \frac{V_j^{(2)}}{V_{ij}} \right)^2 \right\}^{1/2} \tag{4.9}$$

Similarly, for the case where vessel j in waterway 2 is striking vessel i in waterway 1 the apparent collision diameter is:

$$D_j^{(2)} = \frac{L_i^{(1)} V_j^{(2)} \sin\,\theta}{V_{ij}} + \frac{1}{2} B_i^{(1)} \left\{ 1 - \left(\sin\theta \frac{V_j^{(2)}}{V_{ij}} \right)^2 \right\}^{1/2} + \frac{1}{2} B_j^{(2)} \left\{ 1 - \left(\sin\theta \frac{V_i^{(1)}}{V_{ij}} \right)^2 \right\}^{1/2} \qquad (3.10)$$

It is seen that the total collision diameter D_{ij} is the sum of the two apparent collision diameters, i.e.:

$$D_{ij} = D_i^{(1)} + D_j^{(2)}$$

The probability of vessel i in waterway 1 striking vessel j in waterway 2 given a collision may then be determined as

$$P\left[\ \text{vessel}\, i \rightarrow \text{vessel}\, j \,|\, \text{collision}\ \right] = \frac{D_i^{(1)}}{D_{ij}} \qquad (4.12)$$

Similarly, the probability of vessel j in waterway 2 striking vessel i in waterway 1 is found as

$$P\left[\ \text{vessel}\, j \rightarrow \text{vessel}\, i \,|\, \text{collision}\ \right] = \frac{D_j^{(2)}}{D_{ij}} \qquad (4.13)$$

The frequency, $\lambda_{ship-ship}$, of ship-ship collision per time unit is then determined as

$$\lambda_{ship.ship} = P_{C\,i,j}\, N_{G\,i,j} \qquad (4.14)$$

Due to the fact that both of the involved two ships have the possibility of making aversive manoeuvres, the causation probability, P_C, for ship-ship collision is smaller than the one given for grounding and collision against fixed objects, see Section 5.1. Based on collision statistics in Japanese waters, Fujii *et al.* [8] has estimated that for crossing ships $P_c = 1.2 \cdot 10^{-4}$ and for meeting ships in parallel waterways $P_c = 4.9 \cdot 10^{-5}$.

Given the frequency of the (annual) number of collisions $\lambda_{ship-ship}$ the probability of having a collision during time interval Δt can be estimated on the assumption of arrivals of the collisions as points in a Poisson process:

$$P[\text{Collision}] = 1.0 - \exp[-\lambda_{ship\text{-}ship}\, \Delta t] \approx \lambda_{ship\text{-}ship}\, \Delta t \quad \text{for} \quad \lambda_{ship\text{-}ship} \rightarrow 0$$

Provided, of course, that the collision frequency of is time invariant.

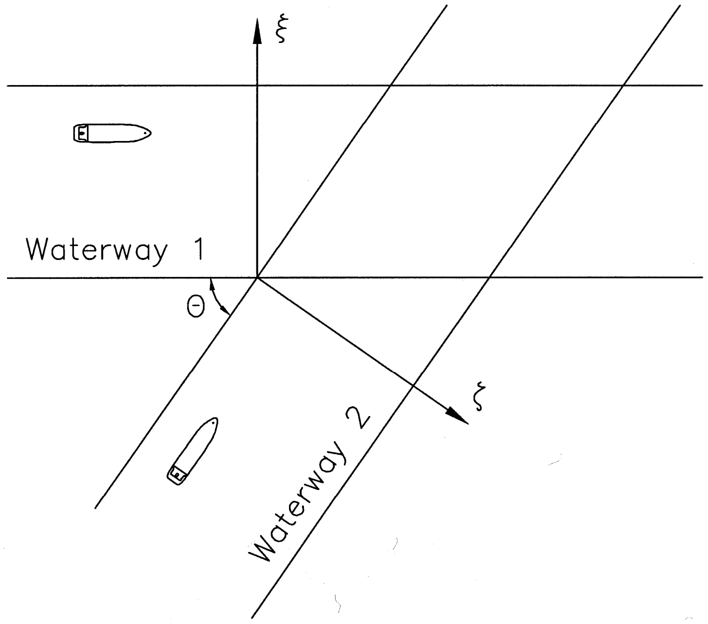


Figure 7 Basic layout of the simulated crossings with results presented in Figure 8 and Figure 9.

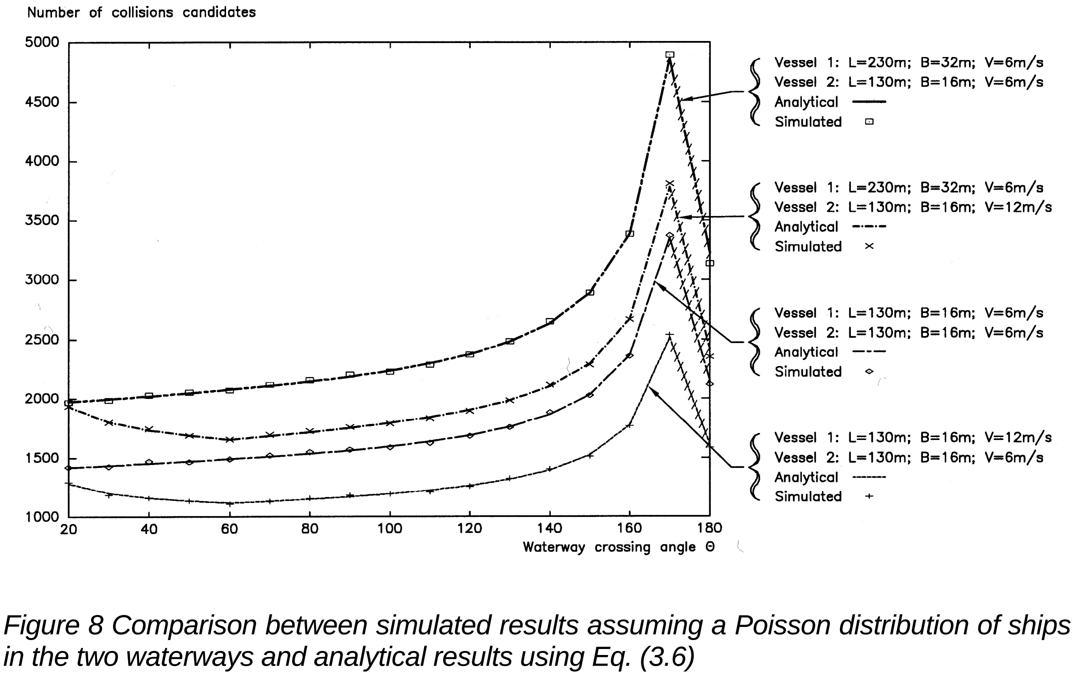


Figure 8 Comparison between simulated results assuming a Poisson distribution of ships in the two waterways and analytical results using Eq. (3.6)

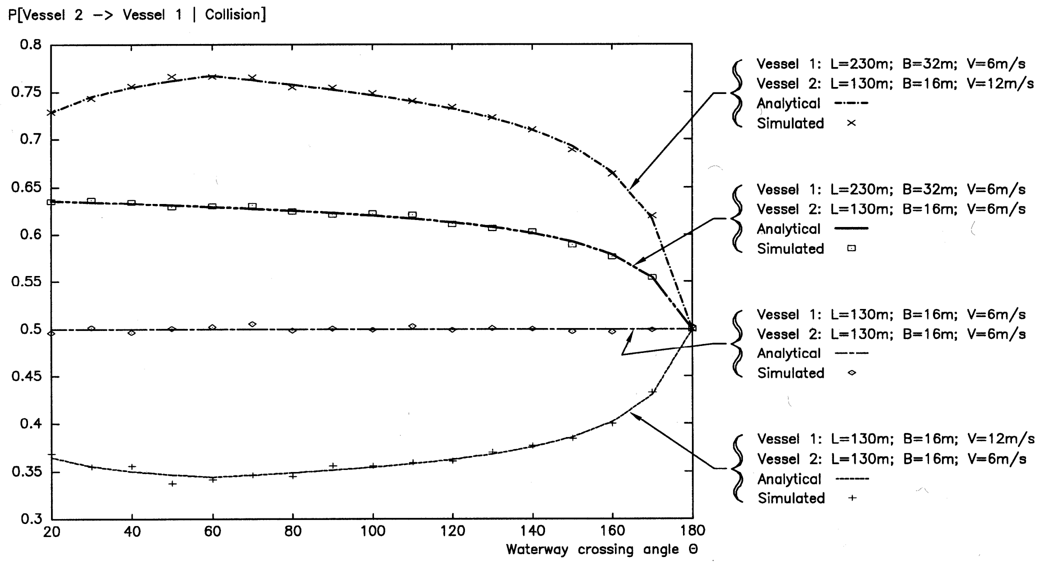


Figure 9 Simulated and analytical results for the probability of vessel 2 colliding with vessel 1 given a collision.

In order to verify the established analytical model and at the same time gain insight in the sensitivity of the number of collision candidates with respect to parameters such as crossing angles θ, ship dimensions, and ship speeds a program has been written which is based on time simulation.

What has been considered is vessels of the same type in waterway 1 crossing the axis ξ, see Figure 7, as points in a Poisson process with intensity Q_1 = 20000 vessels per year. The vessels in waterway 1 are assumed normally distributed over the width of the channel with μ = 100 m and σ = 45 m.

Similar assumptions are made for vessels in waterway 2 crossing the axis ζ in Figure 7. Here Q_2 = 50000 vessels per year and μ = 100 m and σ = 45 m. The vessels in the two waterways are moving with speed V_1 and V_2, respectively.

A time history of +/- one hour of simulated vessels in waterway 1 is kept for matching against simulated vessels in waterway 2, i.e. t_1 - 3600 s < t_2 < 3600 s + t_1. During the simulation it is calculated whether or not the two vessels are colliding. If they are observed to collide, it is further identified which of the vessels is the struck vessel and which is the striking vessel.

Figure 8 shows the number of collision candidates during a period of forty years determined by time simulation and determined by the analytical expression Eq. (3.6) as functions of the angle θ between the two waterways.

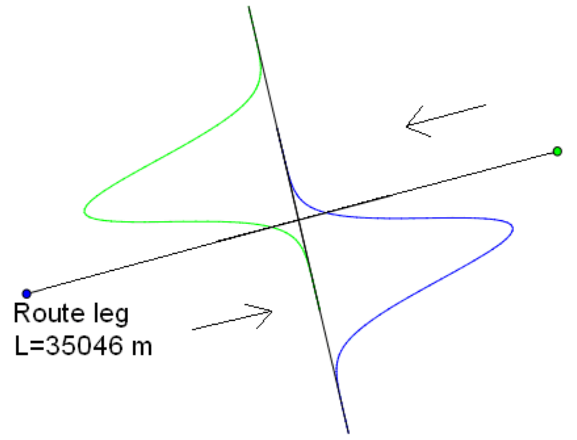
4.1.3 Collision test cases

This subsection describes the result of a series of selected test cases that were analysed by use of the GRISK program and by hand calculation. Only the number of collision candidates is calculated.

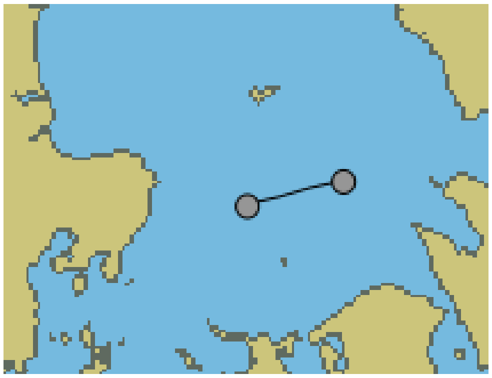
4.1.3.1 Test 1, Head on collision

Test case 1 calculates the number of head on collisions per year. The scenario is:

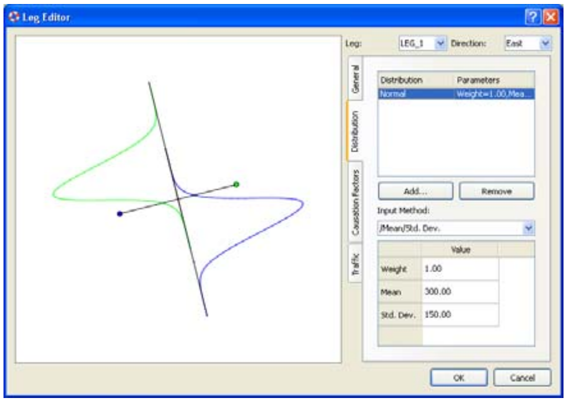
Length of leg	35,046 m
Ships in each direction	10,000
Length of ships	214 m
Breadth of ships	33.4 m
Speed of ships	14.7 knots
Traffic distribution	Normal dist
Mean position from leg	300 m
Standard deviation	150 m
Causation factors	1.0



To calculate this scenario in the BaSSy toolbox, GRISK, do the following steps:



1. Define leg



Leg: LEG_1 Direction: East

Normal Weight=1.00,Mea...

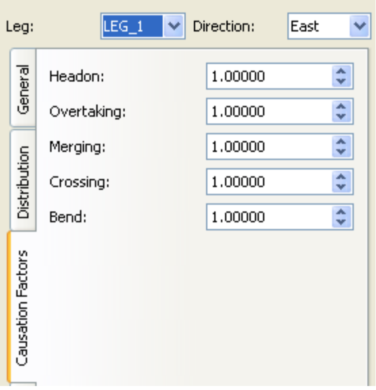
Input Method: Mean/Std. Dev.

Weight 1.00

Mean 300.00

Std. Dev. 150.00

2. Define traffic distribution in each direction



Leg: LEG_1 Direction: East

Headon: 1.00000

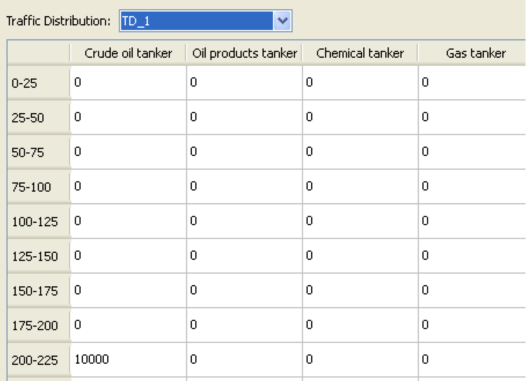
Overtaking: 1.00000

Merging: 1.00000

Crossing: 1.00000

Bend: 1.00000

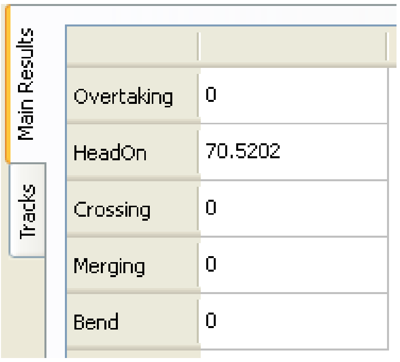
3 .Define causation factors



Traffic Distribution: TD_1

	Crude oil tanker	Oil products tanker	Chemical tanker	Gas tanker
0-25	0	0	0	0
25-50	0	0	0	0
50-75	0	0	0	0
75-100	0	0	0	0
100-125	0	0	0	0
125-150	0	0	0	0
150-175	0	0	0	0
175-200	0	0	0	0
200-225	10000	0	0	0

4. define number of ships in each direction



Overtaking	0
HeadOn	70.5202
Crossing	0
Merging	0
Bend	0

5. Run the job and read results

Note that we here use 10000 crude oil tankers in the length interval 200-225 m. From this length interval and ship type GRISK looks up the breadth and speed using the predefined dimension tables described in the appendix

Hand calculation of the head-on collision scenario

$$N_G^{\text{head-on}} = L_W \sum_{i,j} P_{G\,i,j}(\text{head - on}) \frac{V_{ij}}{V_i^{(1)} V_j^{(2)}} \left(Q_i^{(1)} Q_j^{(2)} \right)$$

$$N_G^{\text{head-on}} = 35{,}046m \sum_{i,j} P_{G\,i,j}(\text{head - on}) \frac{2 \cdot 7.56m/s}{7.56m/s \cdot 7.56m/s} \cdot \frac{(10{,}000 \cdot 10{,}000)}{(360 \cdot 24 \cdot 3600)^2}$$

$$P_{G\,i,j}^{\text{head-on}} = \Phi\left(\frac{\overline{B}_{ij} - \mu_{ij}}{\sigma_{ij}} \right) - \Phi\left(-\frac{\overline{B}_{ij} + \mu_{ij}}{\sigma_{ij}} \right) \quad \sigma_{ij} = \sqrt{\sigma_i^2 + \sigma_j^2} = \sqrt{150^2 + 150^2} = 212.1m$$

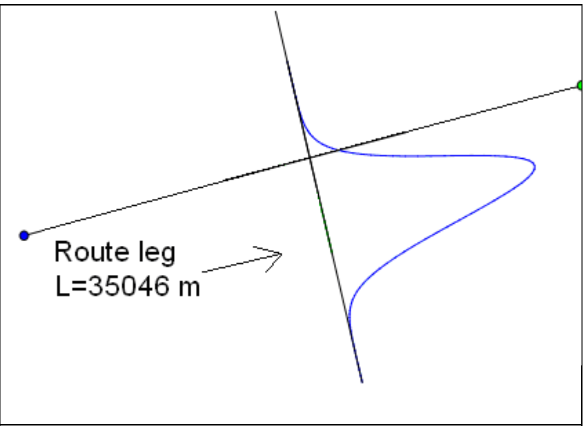
$$P_{G\,i,j}^{\text{head-on}} = \Phi\left(\frac{33.4m - 600m}{212.1m} \right) - \Phi\left(-\frac{33.4 + 600m}{212.1m} \right) = \Phi(-2.67) - \Phi(2.99) = 0.00237$$

$$N_G^{\text{head-on}} = 35{,}046m \sum_{i,j} 0.00237 \cdot 2.646 \cdot 10^{-8} \cdot (360 \cdot 24 \cdot 3600) \ = 70.5$$

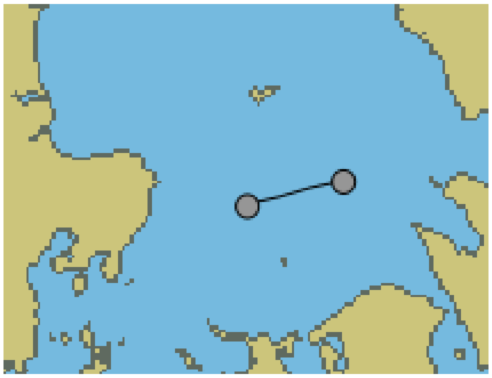
This result is equal to the result calculated by GRISK

4.1.3.2 Test 2: Overtaking collision

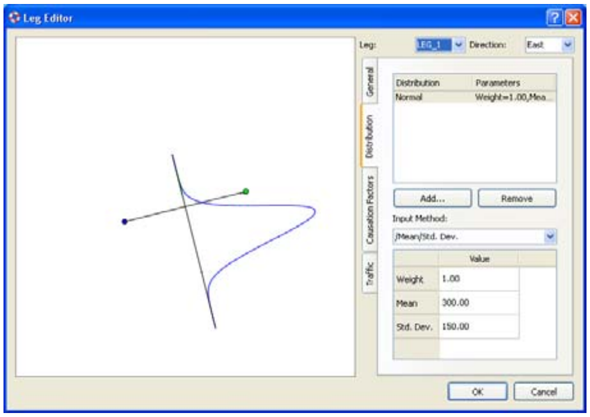
Calculates the number of collisions per year on a leg where ships sail in the same direction but at different speeds. The scenario is:

Length of leg	35,046 m	
Number of ship 1	10,000	
Length of ship 1	214 m	
Breadth of ship 1	33.2 m	
Speed of ship 1	14.7 knots	
Number of ship 2	10,000	
Length of ship 2	162 m	
Breadth of ship 2	25.0 m	
Speed of ship 2	18.9 knots	
Mean position from leg	300 m	
Standard deviation	150 m	
Causation factors	1.0	

To calculate this scenario in GRISK, do the following steps:



1. Define leg



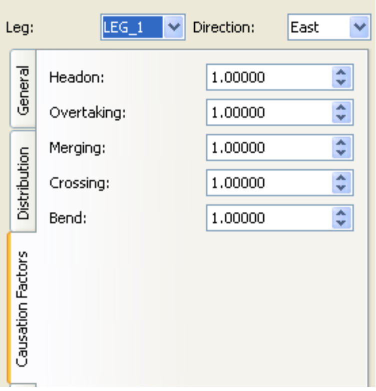
Leg: LEG_1 Direction: East

Distribution	Parameters
Normal	Weight=1.00,Mea...

Input Method: /Mean/Std. Dev.

	Value
Weight	1.00
Mean	300.00
Std. Dev.	150.00

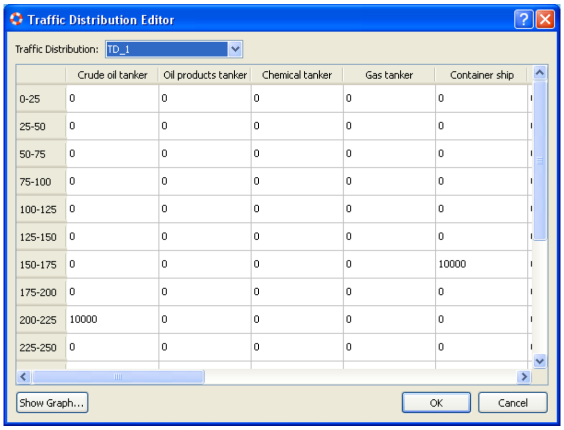
2. Define traffic distribution in each direction



Leg: LEG_1 Direction: East

Headon: 1.00000
Overtaking: 1.00000
Merging: 1.00000
Crossing: 1.00000
Bend: 1.00000

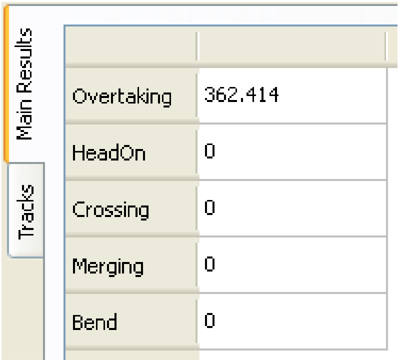
3 .Define causation factors



Traffic Distribution: TD_1

	Crude oil tanker	Oil products tanker	Chemical tanker	Gas tanker	Container ship
0-25	0	0	0	0	0
25-50	0	0	0	0	0
50-75	0	0	0	0	0
75-100	0	0	0	0	0
100-125	0	0	0	0	0
125-150	0	0	0	0	0
150-175	0	0	0	0	10000
175-200	0	0	0	0	0
200-225	10000	0	0	0	0
225-250	0	0	0	0	0

4. define two number of ships



Overtaking	362.414
HeadOn	0
Crossing	0
Merging	0
Bend	0

5. Run the job and read results

Hand calculation of the head-on collision scenario
This only difference to the head on collision calculation is the sign of the two speeds.

$$N_G^{\text{overtaking}} = L_W \sum_{i,j} P_{G\,i,j}(\text{head-on}) \frac{V_{ij}}{V_i^{(1)} V_j^{(2)}} \left(Q_i^{(1)} Q_j^{(2)}\right)$$

$$N_G^{\text{overtaking}} = 35{,}046m \sum_{i,j} P_{G\,i,j}(\text{head-on}) \frac{(9.72-7.56)m/s}{9.72m/s \cdot 7.56m/s} \cdot \frac{10{,}000 \cdot 10{,}000}{(360 \cdot 24 \cdot 3600)^2}$$

$$P_{G\,i,j}^{\text{overtaking}} = \Phi\left(\frac{\overline{B}_{ij} - \mu_{ij}}{\sigma_{ij}}\right) - \Phi\left(-\frac{\overline{B}_{ij} + \mu_{ij}}{\sigma_{ij}}\right)$$

$$\sigma_{ij} = \sqrt{\sigma_i^2 + \sigma_j^2} = \sqrt{150^2 + 150^2} = 212.1m$$

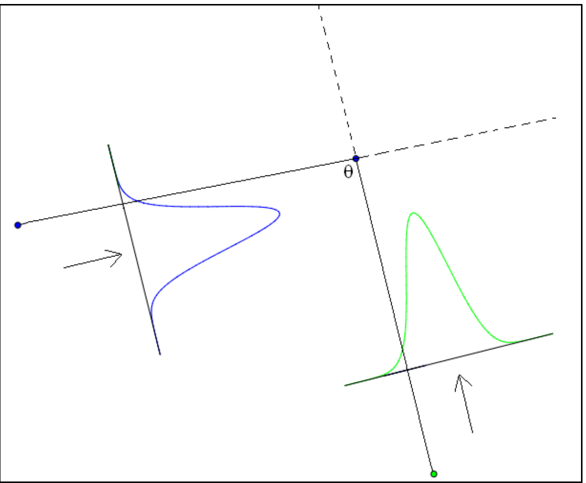
$$P_{G\,i,j}^{\text{overtaking}} = \Phi\left(\frac{(33.39+25)/2m - 0m}{212.1m}\right) - \Phi\left(-\frac{(33.39+25)/2m + 0m}{212.1m}\right) =$$
$$= \Phi(0.138) - \Phi(-0.138) = 0.1095$$

$$N_G^{\text{overtaking}} = 35{,}046m \sum_{i,j} 0.1095 \cdot 3.037 \cdot 10^{-9} \cdot (360 \cdot 24 \cdot 3600) = 362.5$$

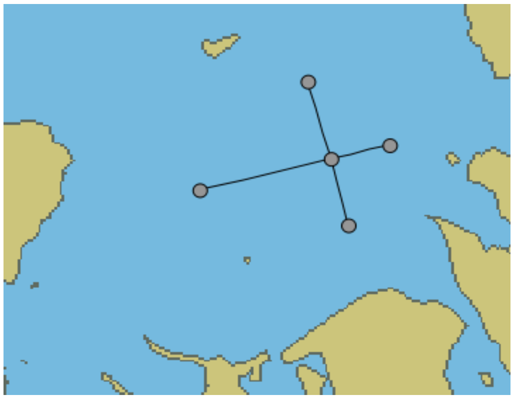
This result is equal to the result calculated by GRISK.

4.1.3.3 Test 3: Crossing collision

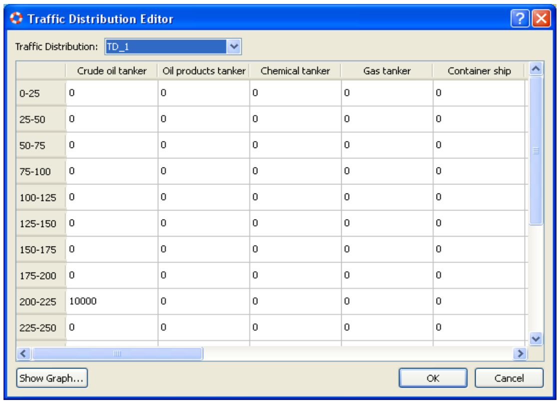
Test case 3 calculates the number of crossing collisions per year. The scenario is:

Ships North going	10,000	
Ships East going	10,000	
Length of ships	200 m	
Breadth of ships	33.4 m	
Speed of ships	14.7 knots	
Angle between legs	88.8 deg	
Causation factors	1.0	

In GRISK this scenario is defined as follows:



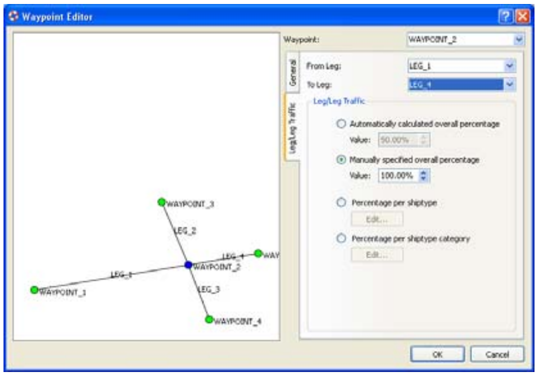
1. Define the legs



Traffic Distribution: TD_1

	Crude oil tanker	Oil products tanker	Chemical tanker	Gas tanker	Container ship
0-25	0	0	0	0	0
25-50	0	0	0	0	0
50-75	0	0	0	0	0
75-100	0	0	0	0	0
100-125	0	0	0	0	0
125-150	0	0	0	0	0
150-175	0	0	0	0	0
175-200	0	0	0	0	0
200-225	10000	0	0	0	0
225-250	0	0	0	0	0

4. Define number of ships on each leg and the causation factors



Waypoint: WAYPOINT_2

From Leg: LEG_1

To Leg: LEG_4

Leg/Leg Traffic

○ Automatically calculated overall percentage

Value: 50.00%

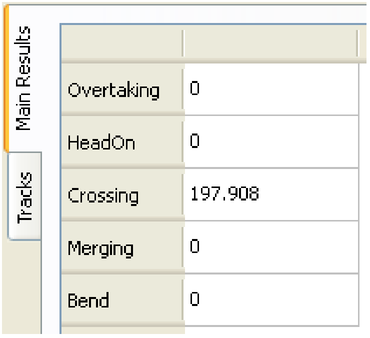
● Manually specified overall percentage

Value: 100.00%

○ Percentage per shiptype

○ Percentage per shiptype category

4. Define how much traffic sails from one leg to the others



Overtaking	0
HeadOn	0
Crossing	197.908
Merging	0
Bend	0

Run the program and read the results

Hand calculation of the crossing collisions scenario

The geometric number of *crossing collisions* candidates for crossing waterways can similarly to Eq. (3.2) be expressed as,

$$N_G^{\text{crossing}} = \sum_{i,j} \frac{Q_i^{(1)} Q_j^{(2)}}{V_i^{(1)} V_j^{(2)}} D_{ij} V_{ij} \frac{1}{\sin\theta} \qquad \text{for} \qquad \theta \neq 0 \qquad (3.6)$$

where $V_{ij} = \sqrt{\left(V_i^{(1)}\right)^2 + \left(V_j^{(2)}\right)^2 - 2 V_i^{(1)} V_j^{(2)} \cos\theta}$ is the relative speed between the vessels and $D_{i,j}$ defines the apparent collision diameter, see Figure 4.

$$V_{ij} = \sqrt{(7.56 m/s)^2 + (7.56 m/s)^2 - 2 \cdot 7.56 \cdot 7.56 \cos(88.8 \deg)} = 10.58 m/s$$

$$D_{ij} = \frac{200 \cdot 7.56 + 200 \cdot 7.56}{10.58} \sin(88.8) + 33.2 \left\{ 1 - \left(\sin(88.8) \frac{7.56}{10.58} \right)^2 \right\}^{1/2}$$

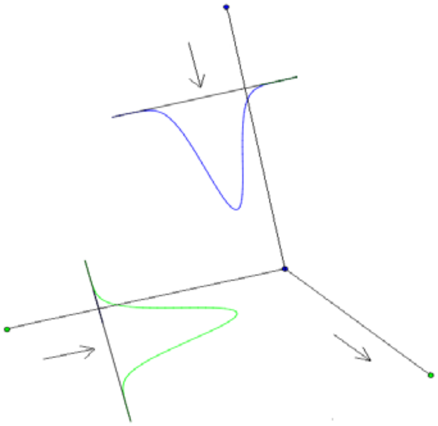
$$+ 33.2 \left\{ 1 - \left(\sin(88.8) \frac{7.56}{10.58} \right)^2 \right\}^{1/2} = 332.5$$

$$N_G^{\text{crossing}} = \sum_{i,j} \frac{10000 \cdot 10000}{7.56 \cdot 7.56 \cdot 360 \cdot 24 \cdot 3600} \cdot 332.5 \cdot 10.58 \cdot \frac{1}{\sin(88.8 \deg)} = 197.8$$

This result is equal to the result calculated by GRISK

4.1.3.4 Test 4: Merging collision

Collision due to merging traffic is calculated as crossing collisions



Merging traffic

4.2 Probability of grounding

Following Pedersen [25], the grounding scenarios may broadly be divided into four main categories, see Figure 10:

I. Ships following the ordinary direct route at normal speed. Accidents in this category are mainly due to human error, but may include ships subject to unexpected problems with the propulsion/steering system that occur in the vicinity of the fixed marine structure or the ground.
II. Ships that failed to change course at a given turning point near the obstacle.
III. Ships taking evasive actions near the obstacle and consequently run aground or collide with the object.
IV. All other track patterns than Cat. I, II and III, for example ships completely out of course due to loss of propulsion.

Figure 10 shows observed grounding locations in a part of the Great Belt in Denmark over a 15-year-period. It is seen that most of the grounding events belong to category I and II but there are also category III and IV groundings which seem to be randomly scattered over the area.

In formulating a theoretical model for the grounding scenario it is expedient to divide the grounding scenario into powered groundings and drifting groundings. Such division eases not only the frequency assessment but also the pursuing consequence assessment.

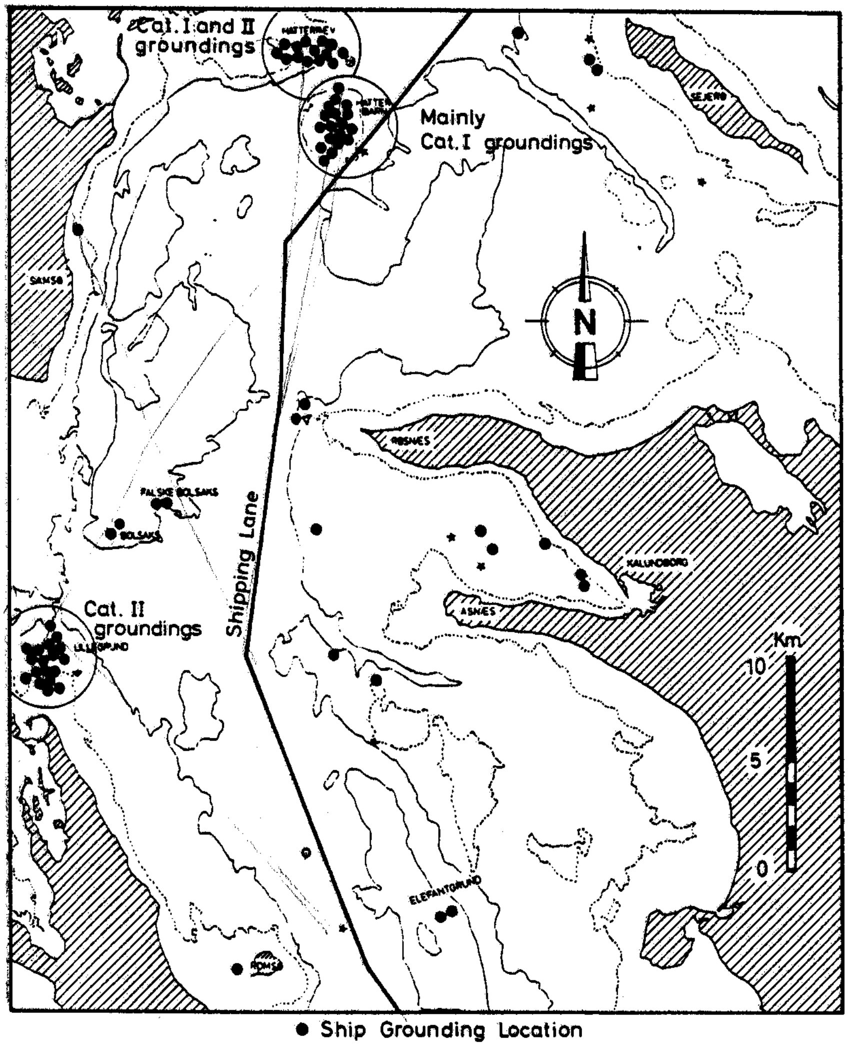


Figure 10 Observed grounding events over a 15-year-period in a Danish Strait, from [25].

In the following, expressions are presented for predicting the expected annual number of grounding events of category I and II accidents. The probability of category III and IV grounding events are today normally found by modification of the traffic distribution along the route. In the present work drifting ships (category IV) are modelled by assuming a drifting direction according to a user specified wind rose. Evasive manoeuvres (category III are not explicitly dealt with in the present version. We revert to these issues later.

Ships in category I and II, following an ordinary route, are distributed over a transverse section of the waterway with some probability density function, $f_i(z)$, where index i refers to a ship class and *z* is the transverse coordinate, see Figure 11. The shape of f_i is a strong function of the considered waterway so a major challenge of the present approach is to define rationally $f_i(z)$ along a given route. Given f_i the number of candidates of grounding events can be calculated as an integral of f_i over the width, $z_{\min}$ to $z_{\max}$, of the obstacle. The hatched area in Figure 11 illustrates this. Most of these candidates will be aware of the danger and take the necessary aversive actions before they hit the obstacle. However, a fraction, P_c, of the candidates will fail to avoid the obstacle, due to for example human and technical errors. The fraction P_c is normally referred to as the "causation probability", and it will be shown later how it can be estimated.

Groundings that are caused by a meeting situations where ships may feel forced to give way, which then subsequent may result in grounding, has not been considered. Such a model requires much more advanced modelling than what is implemented at the present stage. Neither have groundings that are caused by a "rudder stuck" failure. In this case the rudder may either go the extreme starboard/port side or it will get stuck in a central position and cause the vessel either to turn in circles or to follow its path. The model requires more data information before it will be implemented.

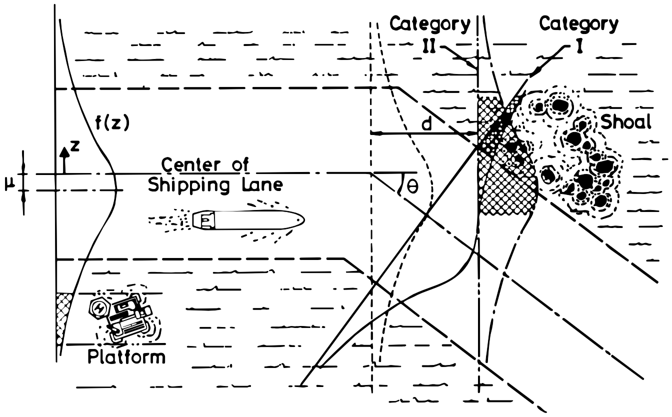


Figure 11 Illustration of model for predicting the expected number of grounding events or collisions with fixed objects on a given ship route, from [25].

4.2.1 Powered grounding

According to the model described above, the expected number of grounding events in Category I and II can be calculated as

$$N_I = \sum_{\text{Ship class, i}} P_{c,i} Q_i \int_{z_{\min}}^{z_{\max}} f_i(z)dz \tag{4.15}$$

$$N_{II} = \sum_{\text{Ship class, i}} P_{c,i} Q_i \exp(-d/a_i) \int_{z_{\min}}^{z_{\max}} f_i(z)dz \tag{4.16}$$

where the following notation has been used:

a_i	Average distance between position checks by the navigator.
d	Distance from the obstacle to the bend in the navigation route varying with the lateral position, *s*, of the ship.
i	Index for ship class, categorised after vessel type and dead weight or length.
$f_i(z)$	Probability density function for the ship traffic
N_I	Expected number of category I grounding events per year.
N_{II}	Expected number of category II grounding events per year.
$P_{c,i}$	Causation probability, i.e. ratio between ships grounding and ships on a grounding course.
Q_i	Number of ships in class *i* passing a cross section of the route per year.
z	Coordinate in the direction perpendicular to the route.
$z_{\min}$, $z_{\max}$	Transverse coordinates for an obstacle.

In the above it is assumed that the event of checking the position of the ship can be described as a Poisson process. Thus, the factor $\exp(-d/a_i)$ represents the probability of the navigator not checking the position from the bend to the obstacle. The average distance between position checks is conveniently expressed in terms of the expected value of the time between position checks, λ, (approximately equal to 3 minutes) whereby the factor $\exp(-d/a_i)$ becomes a function of the ship speed, $a_i = \lambda V$. Eq. (4.16) is only correct for the case when the ground is orthogonal to the sailing route, which rarely is the case. In the event of the ground not being perpendicular to the sailing direction, but inclined so that the distance d from the bend to the ground may be expressed as $d = az + b$. In the event that the two traffic spread distributions follow a normal distribution then Eq. (4.16) can be simplified to

$$N_{II} = \sum_{\text{Ship class, i}} P_{c,i} Q_i \left[\frac{1}{2} \exp\left(\frac{a^2\sigma^2 - 2b\lambda V}{2\lambda^2 V^2} \right) \left\{ 2\Phi\left(\frac{z\lambda V + a\sigma^2}{\sigma\lambda V} \right) - 1 \right\} \right]_{z_{\min}}^{z_{\max}} \qquad (4.17)$$

For other type of distributions, especially for mixed distributions, it is not a straight forward task to formulate a closed form solution to the number of grounding candidates. For such distributions the integral can be effectively solved by solving part of the integral analytical and then performing a numerical integration over the remaining variables.

With the formulation above the expected number of annual grounding events becomes a function of traffic distributions, bottom topology, route layout etc. It is seen from Eq. (4.15), (4.16) and (4.17) that another important parameter is the causation factor, P_c, determining how large a fraction of the accident candidates actually run aground or hit the obstacle. Chapter 5 gives a thorough presentation of the causation factor. Often the causation probability is selected to be in the vicinity to $P_c = 2 \cdot 10^{-4}$.

The calculated expected number of yearly (powered) grounding events, $N_g = N_I + N_{II}$, can be considered as the intensity in a Poisson process. The probability of no grounding events in one year is then

$$P\left[Grounding\right] = 1 - \exp(-N_g) \tag{4.18}$$

4.2.2 Drifting grounding

The probability of category III (evasive manoeuvres) and category IV (drifting ships) grounding events are today typically found by modification of the traffic distribution along the route. Combining a 98% Gaussian distribution and a 2% uniform distribution performs the modification of the traffic distribution; see e.g. Gluver and Olsen [12] or Karlson *et al.* [19]. The value of 2% is based on engineering judgement and the results are dependent on the value especially in narrow restricted waters. Although this approach is very fast and easy to implement, it is considered to be too coarse a model that does not properly account for the physical effects that governs the drifting problem. In the section the implemented drifting model is defined.

The two main causes for a ship to be not under command are rudder stuck and blackout of the main engine. Rudder stuck will not be dealt with in this study. Most ships experiences of the order of one black out of the main engine per year. The number of any blackout for a given ship will typically lie in the interval from 0.1 to 2 blackouts per year. The actual frequency of blackouts depends on the degree of redundancy and the general maintenance level of the ships. Ferries and ro/ro vessels generally have a high degree of built-in redundancy into the engine room (2 to 4 propulsion units) and hence they have a low frequency of blackouts. For many other single propulsion unit ships the frequency of blackouts are higher.

In the present study the following blackout frequencies are selected as base values:

Vessel type	Annual frequency	Hourly frequency
Passenger / Ro-Ro	$0.1\ y^{-1}$	$1.15 \cdot 10^{-5}\ h^{-1}$
Other vessels	$0.75\ y^{-1}$	$8.56 \cdot 10^{-5}\ h^{-1}$

A blackout may be caused by contaminated fuel, internal fault in the main engine, or failure of the electrical system. The seriousness of the incident depends on the location at which the blackout occurs, the wind direction, wind speed, and of course the duration of the blackout (that is the drifting time). If a high degree of redundancy has been built into the engine room then the command over vessel may be regained in relative short time. In other situations, the drifting time may be of order of hours. The drifting ship will drift side ways and it will drift (approximately) in the direction of the wind.

The drifting scenario may be remediated either by repairing the problem, by anchoring the vessel or by calling a tug boat.

Failure of propulsion machinery may occur at any location along the waterway. Assuming that blackouts occur as points in a Poisson process then the probability of having a blackout along a leg segment of length L_{segment} is:

$$P_{\text{blackout}}\left(L_{\text{segment}}\right) = 1 - \exp\left(-\lambda_{\text{blackout}} \frac{L_{\text{segment}}}{v_{\text{vessel}}}\right)$$

In which $\lambda_{\text{blackout}}$ is the frequency of blackout and v_{vessel} is the operational speed of the vessel. The number of drifting groundings, $N_{\text{grounding}}^{\text{drift}}$, out of the N_{ship} candidates of a particular ship type and size, can be calculated as

$$N_{\text{grounding}}^{\text{drift}} = N_{\text{ship}} \int_{\psi=0}^{360} P_{\text{wind}}(\psi)$$

$$\sum_{\text{All segments}} P_{\text{blackout}}(L_{\text{segment}}) \int_{x=0}^{L_{\text{segment}}} \int_{\text{All}\, v_{\text{drift}}} P_{\text{no repair}}\left(t_{\text{ground}} \mid \mathbf{Z}\right) P_{\text{no anchoring}}\left(t_{\text{ground}} \mid \mathbf{Z}\right) f(v_{\text{drift}})\, \mathrm{d}v_{\text{drift}}\, \mathrm{d}x\, \mathrm{d}\psi$$

In which $P_{\text{wind}}(\psi)$ defines the probability of having wind coming from direction ψ. The probability of no repair is defined by the complementary distribution function of the repair time distribution. The default repair time distribution is modeled as a Weibull distribution,

$$F_{\text{repair}}(t) = 1 - \exp\left(-a\, t^{b}\right) \quad \text{and} \quad F_{\text{no repair}}(t) = \exp\left(-a\, t^{b}\right)$$

with scale parameter $a = 1.05$ and shape parameter $b = 0.9$, which gives a mean value of 1 hour and standard deviation of 1.13 hour. The distribution for the repair time has not been justified by data, but is defined based on an engineering assessment in discussion with two experienced first engineers having several years of operational experience. The distribution function is shown in the figure below.

The time to grounding is defined as $t_{\text{ground}} = d_{\text{ground}} / v_{\text{drift}}$, in which v_{drift} is the (uncertain) drifting speed and $d_{\text{ground}}(x)$ defines the distance from the leg segment to the ground. The drifting speed is defined through its probability density function $f(v_{\text{drift}})$, which possible may defined as a function of the wind speed and the vessel type (at present this is not implemented in the GRISK program. At present the drifting speed is assumed to be uniformly distributed in the interval [1 m/s; 3 m/s]. The conditional vector $\mathbf{Z} = \left\{ x, \psi, v_{\text{drift}} \right\}$ defines the parameters on which the time to grounding is conditioned.

Depending on the area and the vessel drifting speed of the, the captain may decide to drop the anchor to avoid the vessel is drifting on ground. At present the probability of no anchoring is set to 1. In future when more information has been gathered this model will be revised.

The total number of groundings from all categories is calculated as

$$N_g = N_I + N_{II} + N_{III} + N_{IV}$$

4.3 Assessing the traffic spread across the route

With access to AIS data it is a relative straight forward task to assess the probability distribution of the traffic spread across the route as well as the number and the composition of the vessel traffic. When such data are not available it is a quite involved task to identify the needed data. Only little guidance has been found in literature on the geometric distribution of the traffic. Typically a normal distribution is selected. Gluver and Olsen [12] proposed to apply a standard deviation equal to ship length. Alternatively the standard deviation of the Gaussian distribution can be selected to be proportional to the vessel breadth, $\sigma = 3{,}65B$. This choice corresponds to a 96% probability of the vessel being within $\pm 7.5B$ of the planned route, which again reflects the zone within which the navigator of the vessel identifies safe operation. In the study by Karlson *et al.* [19] the standard deviation of the Gaussian distribution was chosen to 40% of the navigational channel.

4.4 Calculation procedure for estimating the collision frequency

Based on the mathematical models for estimating the collision grounding frequencies described in the previous sections a computer program has been written for calculation of grounding and collision frequencies in specific waterways where the ship traffic distribution is known.

As earlier described, the idea behind the procedure is that vessels are operating on specific route. The traffic routes are built of a series of waypoints that are connected by legs. On each leg the number of vessels as a function of size and type and their overall spreading are defined. Each leg may be connected to zero, one or more other segments at its end points. In principle three different types of collisions can occur. One type of collision is head-on induced collisions due to two way traffic in the straight waterway segments or overtaking taking collisions as shown in Figure 2. As seen from Eq. (4.4) then the traffic distributions are importance in this case. Another type of collision occurs at bends where only two straight route segments intersect, see Figure 12. At such an intersection a ship can become a collision candidate if the course is not changed at the intersection. This probability of omission P_0 is taken as 0.01.

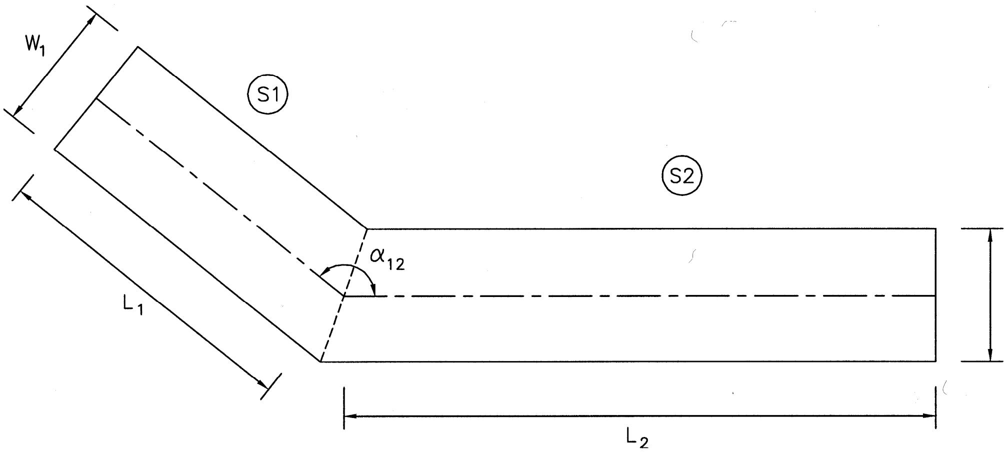


Figure 12 Intersection between two straight waterway segments.

Finally, when more than two legs meet at a waypoint the model calculates the probability for crossing collisions, as indicated in Figure 3. Dependent on how the vessel traffic on the legs meets each other, the scenario will be characterized either as either a crossing collision, a merging collision, or a bend collision.

For each leg the identified number of collision candidates related to head-on, bends, and crossings is calculated for each vessel type and is subsequent multiplied by a causation factor. The following causation factors inspired by Fujii *et al.* [8]:

P[head on] $= 4.9 \cdot 10^{-5}$
P[bend] $= 1.3 \cdot 10^{-4}$
P[crossing] $= 1.3 \cdot 10^{-4}$

These values for the causation factor are typical values for well regulated ship traffic in Japan. The causation factor will be a function of visibility, darkness, current and wind in the actual geographical area. All these factors suggest that larger values should be used around the Nordic countries. However, Fujii has also observed that passenger ferries have smaller collision probabilities than ordinary merchant vessels. This is due to the navigator awareness of the area and the fact that there are two navigator onboard passenger ferries. The following chapter discusses the assessment of the causation probability in more detail. The causation factors suggested used in the present study are presented in section 5.3.

4.5 Combined causation factor $P_{C\,i,j}$

The causation probability, $P_{C\,i,j}$, represents the probability that none of the two officers on watch on the two vessels manage to react in time and avoid the collision. This implies that the conditions present on both vessels are of importance in the determination of the magnitude of the causation joint factor. This concept is illustrated by a Bayesian network model in a subsequent section. Different conditions may be present that lead to higher (or lower) safety standards compared to the average ship. This could for instance be the presence of a pilot, improved bridge layout and navigational equipment, or the presence of two navigators as is the case on most passenger ferries. The presence of such safety increasing conditions will imply that the joint causation factor, $P_{C\,i,j}$, for the two vessels will decrease. In the study “Oil and Chemical Spills is Danish waters” it was proposed to compile the joint causation factor as

$$P_{C\,i,j} = \sqrt{P_{C\,i} \times P_{C\,j}} \tag{3.15}$$

This is a justifiable pragmatic approach that assures a balance between failures of the navigational watch keeping on the two vessels.

5. CAUSATION PROBABILITY

This chapter presents a comprehensive collection of causation probabilities that have been proposed in literature. Further, a risk model that may be used for evaluating the causation probability is presented. Inadequacies of a frequently cited risk model are discussed and instead we propose to apply Bayesian Networks. A Bayesian Network for obtaining the causation factor for ship-ship collision is established, and the results are compared to available statistics, where good agreement was found.

5.1 Causation probabilities from literature

Larsen [20] performed a comprehensive study on defined causation probabilities in his study of ship collisions with bridges. Although the study primarily addresses ship-bridge collisions, Larsen [20] also presented available causation probabilities for ship grounding and ship-ship collisions. The table below represents an organised table of his review, which further has been extended with some results not given in [20]. References to these are given in the present note. The full references to the authors identified by Larsen [20], will not be given here but may be found in section 5.3 of reference [20].

Vessel grounding

Location	**P_c [$\times 10^{-4}$]**	**Comment**	**Reference:** see [20] for ref.
Japanese Straits	[1.0; 6.3]	Collisions and grounding	Fujii
Japanese Straits	1.58		Fujii & Mizuki [9]
Japanese Straits	[0.8; 4.3]		Matsui
Dover Strait	1.55	No traffic separation	MacDuff [21]
Dover Strait	1.41	With traffic separation	MacDuff [21]
Strait of Gibraltar	2.2		COWIconsult
Øresund, Denmark	2.0		Karlson *et al.* [19]

Ship-ship collisions

Location	**P_c [$\times 10^{-4}$]**	**Comment**	**Reference:** see [20] for ref.
Dover Strait	5.18	Head-on, no traffic separation	MacDuff [21]
Dover Strait	3.15	Head-on, with traffic separation	MacDuff [21]
Øresund, Denmark	0.27	Head on	Karlson *et al.* [19]
Japanese Straits	0.49	Head on	Fujii & Mizuki [9]
Japanese Straits	1.23	Crossings	Fujii & Mizuki [9]
Dover Strait	1.11	Crossings, no traffic separation	MacDuff [21]
Dover Strait	0.95	Crossings, with traffic separation	MacDuff [21]
Strait of Gibraltar	1.2		COWIconsult
Japanese Straits	1.10	Overtaking	Fujii & Mizuki [9]
Great Belt, Denmark	1.30	At bends in lanes	Pedersen *et al.* [24]
Danish waters	3.0	Head-on and overtaking Crossings also?	COWIconsult Oil and Chemical Spills, 2007

Ship-bridge collisions			
Location	**P_c [$\times 10^{-4}$]**	**Comment**	**Reference:** see [20] for ref.
Great Belt	0.4	Traffic regulations, marking of route, detectability	Larsen
Great Belt East and West Bridge	1.1	Having pilot on board	COWIconsult
Great Belt East and West Bridge	3.2	Without pilot on board	COWIconsult
Tasman Bridge	[0.7; 1.0]	Visibility, env. conditions, human error, mechanical failure, traffic intensity	Maunsell and Partners
Sunshine Skyway Bridge, Florida	0.5	Traffic density, use of pilots, traffic restrictions	COWIconsult
Annacis Island Bridge, Fraser River, British Columbia	3.6		CBA-Buckland and Taylor
Sunshine Skyway Bridge, Florida	1.3	Ships only	Knott *et al.*
Sunshine Skyway Bridge, Florida	2.0	Barges only	Knott *et al.*
Francis Scott Key Bridge	1.0	Ships only	Knott *et al.*
Francis Scott Key Bridge	2.0	Barges only	Knott *et al.*
Wm Preston Lane, Jr. Men. Bridge, Maryland	1.0	Ships only	Knott *et al.*
Wm Preston Lane, Jr. Men. Bridge, Maryland	2.0	Barges only	Knott *et al.*
Chesapeake Bay Bridges and Tunnels, Virginia	0.7		Knott *et al.*
Dames Point Bridge, Florida	1.3	Ships only	Knott *et al.*
Dames Point Bridge, Florida	4.1	Barges only	Knott *et al.*
Vicksburg Bridge, Mississippi River	5.4		Modjeski & Masters
Huey P. Long Bridge, Mississippi River	2.5		Modjeski & Masters
Greater New Orleans Bridge, Mississippi River	1.3		Modjeski & Masters
Strait of Gibraltar	0.6	Improved traffic safety	COWIconsult
Japanese Straits	1.86		Fujii & Mizuki [9]

The values of the causation probabilities by Fujii and Mizuki [9] given in the tables above are mean values. Fujii and Mizuki [9] have given the following ranges:

$\log P_c = -4.31 \pm 0.35$ for head-on collisions
$\log P_c = -3.96 \pm 0.36$ for collisions in overtaking
$\log P_c = -3.89 \pm 0.34$ for collisions in crossing
$\log P_c = -3.80 \pm 0.26$ for grounding
$\log P_c = -3.73 \pm 0.36$ for collisions with objects

Further, Fujii and Mizuki [9] states that the above given causation probabilities are obtained for a frequency of visibility less than 1 km that is equal to 263 hours pr. year (i.e. 3%). They further state that the influence of low visibility on the causation probability is approximately proportional to the inverse of the visibility. Finally, they suggest to multiply the above given causation probabilities with a factor of 2 if the frequency of visibility less than 1 km. is in the range of 3% to 10%, and a factor of 8 if it is in the range of 10% to 30%.

5.2 Risk model for obtaining the causation probability

It is virtually impossible to formulate a full risk analysis that properly takes all relevant aspects into account. The modelling should, however, account for a subset as large as possible of the potential error mechanisms. This section describes the traditional risk analytical approach for obtaining the causation probability. We discuss the drawbacks of the traditional formulation and suggest applying Bayesian Network. The subsequent Chapter 6 describes aspects that should be considered in the modelling.

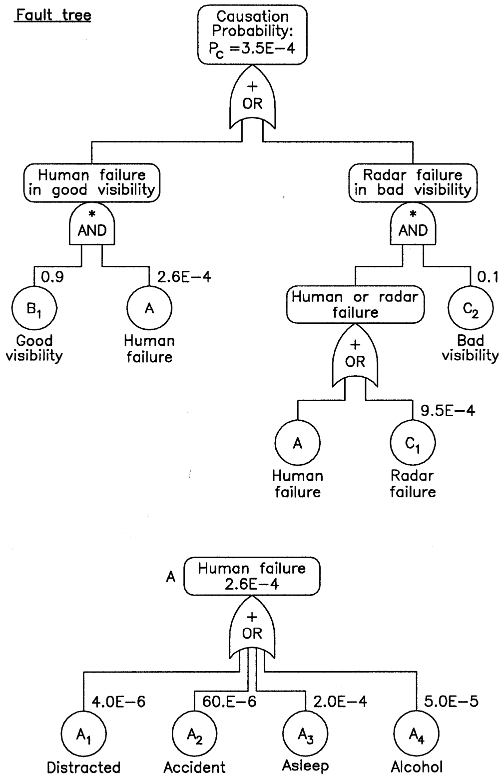


Figure 13 Fault tree for causation probability P_c for collision against fixed object.

5.2.1 Traditional approach

The traditional approach for calculation of P_c (i.e. analysing the cause leading to human inaction or external failures) is to formulate a fault tree or an event tree analysis, see Haugen [13], as shown in Figure 13. From this fault tree it is found that the causation probability P_c can be expressed as

$$P_C = X_A + (1 - X_A)X_{C1}X_{C2}$$

where

X_A is the probability of human failure
X_{C1} is the probability of radar failure, which will depend on vessel size, age, nationality, etc.
X_{C2} is the fraction of the year with low visibility.

By application of such fault tree analyses for estimation of the causation probability, it is possible to examine the beneficial effect of new bridge procedures, of having a pilot on board, or of introducing a VTS system in certain geographical areas. Olsen *et al.* [22] studied the effect of a VTS system by an event tree analysis, see Section 6.2.1.

When inspecting the above fault tree it is questionable whether the modelling actually captures any of the important failure mechanism relevant for the considered critical situation. Factors that relate to navigational complications are not included in the analysis, although these are of importance for the relevant set of human errors. Moreover, it is seen that human failure contributes with 75% ($2.6 \cdot 10^{-4}$) to the causation probability. The dominance of the human failure is in agreement with observations. However, the "Asleep" node is the dominant contributor ($2.0 \cdot 10^{-4}$) and it accounts for 60% of the causation probability. Although the dominating cause may be attributed to human errors this does not seem to be correct as high vigilance is expected in confined navigational areas. An important concern of the fault tree modelling is that the human factor model does not capture the relevant tasks that must be considered in the considered critical situation.

5.2.2 Using Bayesian Networks

Most practical risk analysis problems are characterised by a large set of interrelated uncertain quantities and alternatives. Within the conventional risk analysis different methods such as fault tree analysis and event tree analysis have been developed to address these problems. A fault tree analysis seeks the causes of a given event, and an event tree analysis seeks the consequences of a given event. The two analysis techniques are supplementary methods, and when applied correctly the formulated model may reveal the entire probability structure of the model. Both fault tree analysis and event tree analysis – applied separately and combined – have in the past with success been used in the evaluation of the risk of various hazardous activities. Unfortunately, both fault tree and event tree analyses do have their drawbacks. Firstly, it is difficult to include conditional dependencies and mutually exclusive events in a fault tree analysis (a conditional dependency is, for example, the dependence of the visibility on the weather; mutually exclusive events are, for example, good weather and storm). If conditional dependencies and mutually exclusive events are included in a fault tree analysis the implementation and the pursuing analysis must be performed with utmost care. Secondly, the size of an event tree increases exponentially in the number of variables. Thirdly, if the analysis should capture the primary failure mechanism, the global model, which is combined fault trees and event trees, generally becomes so big that it is virtually impossible for third parties (and sometimes even for first parties) to validate the model.

Here we advocate for using Bayesian Networks as the risk modelling and analysis tool. A Bayesian Network is a graphical representation of uncertain quantities (and decisions) that explicitly reveals the probabilistic dependence between the set of variables and the flow of information in the model. A Bayesian Network is designed as a knowledge representation of the considered problem and may therefore be considered as the proper vehicle to bridge the gap between analysis and formulation.

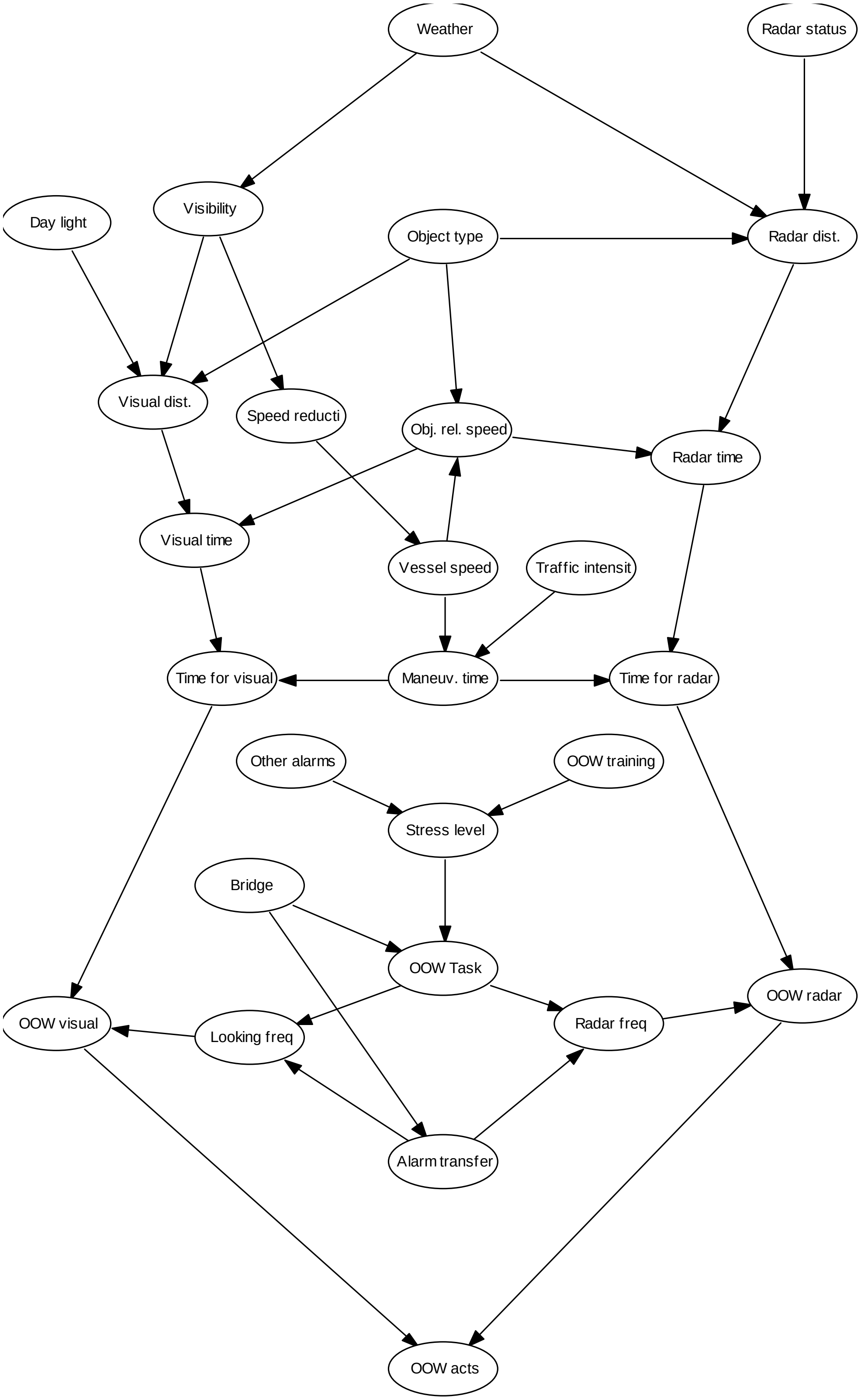


Figure 14 Example for Bayesian Network for a navigating officer reacts in the event of being on collision course with an object, from Friis Hansen and Pedersen [10].

A Bayesian Network is a network with directed arcs and no cycles. The nodes (to which the arcs point) represent random variables and decisions. Arcs into random variables indicate probabilistic dependence, while arcs into decisions specify the information available at the time of the decision. As an example, one node in the network may represent the weather, whereas another may represent the visibility. An arc from weather to visibility indicates that visibility is conditionally dependent on weather; see Figure 14. The diagram is compact and intuitive, emphasising the relationship among the variables, and yet it represents a complete probabilistic description of the problem. For example, it is easy to convert any event tree or fault tree into a Bayesian Network. Conversely, it may not always be an easy task to convert a Bayesian Network into a combined fault tree and event tree, although theoretically possible.

A drawback of Bayesian Network is that they require the state space of the random variables (the nodes) to be defined as discrete states. In our above-mentioned example of weather and visibility, the state space of weather may easily be discretised into states as good weather, storm, etc., whereas the state for visibility more naturally would have been defined as a continuous state space. The Bayesian Network modelling does, unfortunately, require the state space of visibility to be discretised in ranges as for example, 0 to 1 km, 1 to 2 km, etc. Although this is mentioned as a drawback, neither fault trees nor event trees offer any better alternatives. A consequence of the discretisation is partly that the result of the Bayesian Network may be sensitive to the selected discretisation, and partly that the calculations involved in the evaluation of the Bayesian Network grow almost exponentially in the number of states of the nodes. The latter is a consequence of Bayesian Networks encodes the entire probabilistic structure of the problem.

A focus on the causal relationship among the variables most effectively does the building of a Bayesian Network. This implies that a Bayesian Network becomes a reasonably realistic model of the problem domain, which is useful when we try to get an understanding about a problem domain. In addition, knowledge of causal relationships allows us to make predictions in the presence of interventions. Last, but not least, the model building through causal relationship makes it much easier to validate and convey the model to third parties. We will not give any details here on how Bayesian Networks are analysed. Instead reference is left to Jensen [18] and Pearl [23].

The Bayesian Network described above is taken from Friis Hansen and Pedersen [10] where a comparative risk evaluation of traditional watch keeping and one-watch keeping has taken pace. The results of the modelling were compared to observations, and good agreement was obtained. Here we extend the modelling to also cover ship-ship collisions.

5.2.3 Bayesian Network for ship-ship collisions

The network for predicting the causation factor for ship-ship collisions is rooted in the network shown in Figure 14. The Bayesian Network was extended to model two ships, i.e. ship-ship collision situations. The network used for this analysis is presented as Figure 15. It is seen that this Bayesian Network take into account the correlation between the two vessels, that is, they have to detect each other under the same conditions. Although the network appears complicated, the elements from the basic network in Figure 14 are recognised. It is noted that the to more isolated groups in the lower part of the network models the behaviour on the two bridges, whereas the central group in the upper part of the figure models the two vessel that the two vessels has to be detected by each other.

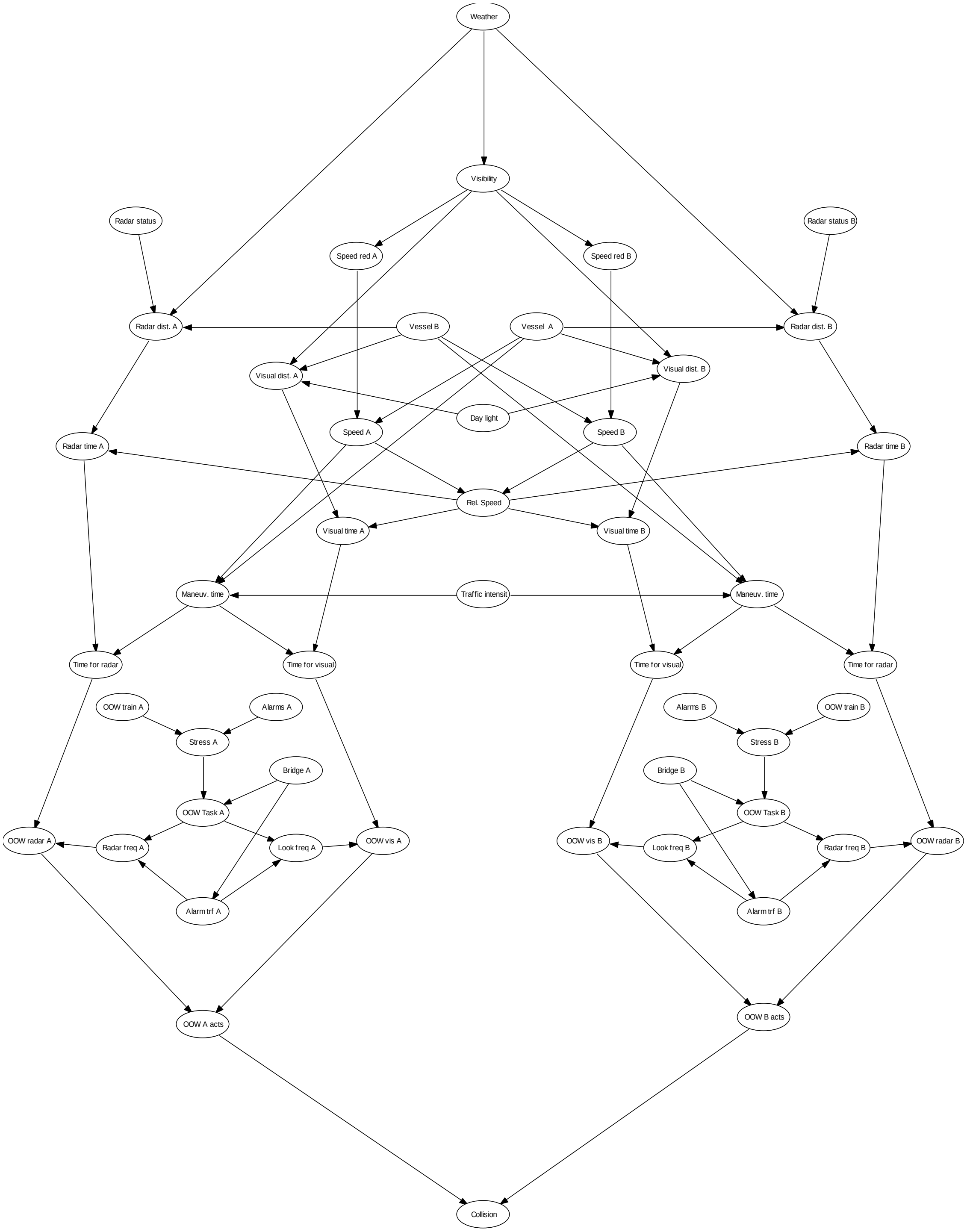


Figure 15 Bayesian Network model for ship-ship collisions accounting for the correlation between the two vessels.

Table 1 shows the calculated causation factors for all the combinations of meetings between large vessels with conventional bridge layout and vessels equipped for sole look-out. It is seen that the calculated causation factor for meetings between conventional vessels is found to be, [10],

$$P_c = 9.00 \cdot 10^{-5}.$$

This value can be compared with observed causation probabilities determined from large data sets published by Fujii et al. [9]. These observed values are given in Table 2. In Table 3 the different headings have been weighed to obtain one global causation factor. The result is that the observations indicate that the causation factor is close to

$$P_c = 8.41 \cdot 10^{-5}$$

That is a factor which is very close to the causation factor $P_c = 9.00\ 10^{-5}$ calculated by the Bayesian Network procedure for conventional vessels operating in geographical areas where the frequency of visibility less than 1 km is 3%.

The modelling illustrates that it indeed is possible to establish a realistic modelling of the causation probability.

Table 1 Causation factors determined by Bayesian Network

	Conventional	**Solo Watch**
Conventional	$9.00\ 10^{-5}$	$7.55\ 10^{-5}$
Solo Watch	$4.30\ 10^{-5}$	$3\ 10^{-5}$

Table 2 Causation Probabilities from Fujii and Mizuki's observations, Ref. [9].

	Log P	**+/-**	**P**
Head-on	-4.31	0.35	$4.90 \cdot 10^{-5}$
Overtaking	-3.96	0.36	$1.10 \cdot 10^{-4}$
Crossings	-3.89	0.34	$1.29 \cdot 10^{-4}$
Grounding	-3.80	0.26	$1.59 \cdot 10^{-4}$
Object	-3.73	0.36	$1.86 \cdot 10^{-4}$

Table 3 Weighing Factors for headings:

Factor	$P \cdot f$
0.5	$2.45 \cdot 10^{-5}$
0.25	$2.74 \cdot 10^{-5}$
0.25	$3.22 \cdot 10^{-5}$

5.3 Default values used in GRISK

The following default values have been selected in GRISK:

Condition	Causation factor
Head on collisions	$0.5 \cdot 10^{-4}$
Overtaking collisions	$1.1 \cdot 10^{-4}$
Crossing collisions	$1.3 \cdot 10^{-4}$
Collisions in bend	$1.3 \cdot 10^{-4}$
Collisions in merging	$1.3 \cdot 10^{-4}$
Grounding – forget to turn	$1.6 \cdot 10^{-4}$
Mean time between checks after missed turn	180 seconds

This value setting is mainly rooted in the observations Fujii and Mizuki's, Ref. [9]

6. FACTORS THAT INFLUENCE THE CAUSATION PROBABILITY

As seen from the Bayesian Network analysis of the ship-ship collision, Section 5.2.3 above, it is indeed possible to accurately model the causation probability. It is, however, very important that level of detail in the model is at a satisfactory level such that the results of the model becomes plausible. In this chapter we list some of the factors that influence the causation probability.

6.1 Reported causes for grounding and collision

Several researchers have published reports on causes for marine accidents. All studies define that the cause of a grounding or collision may be summarised crudely into the following four main groups:

1. Due to failure in manoeuvring, including inaccurate positioning and poor lookout.
2. Due to incapacitation of personnel such as doze, drunkenness engaged in other tasks and sudden illness. Doze has been identified as one of the main causes for grounding.
3. Due to technical problems with engine, steering gear, or navigational instruments.
4. Due to environmental causes, such as visibility, wind, or waves.

Group 1 and 2 in the list above represent the contribution from human errors. Unquestionable, human error is an important cause to navigational accidents – perhaps dominant, as it is quoted that human errors account for at least[2] 80% of all accidents. More precisely it could be stated that approximately 80% of navigational accidents involves at least some human errors or questionable judgements rounded in organisational factors. What complicates the assessment is that the blame (or cause) for an accident can be allocated in different ways according to the perspective of the investigator. Typically a serious accidents start from basic human errors but the seriousness of the accident is rather a compound of a set of technical failure, operators' error, fundamental design errors, and management errors.

Therefore, any realistic modelling must provide a detailed representation of human error in order to be successful. Unfortunately, the human error mechanisms differ from technical or environmental cause (viz. the remaining 20%), and are – in fact – not yet well understood. A major problem in this respect is that there exists no such thing as a recipe for doing a specific task in the right way (e.g. performing a turn). In an examination of a series of manoeuvring simulation that have led to a grounding accident, Thau [29] found that the primary human error leading to the accident often occurred more than 10 minutes prior to the accident. Contrary, technical or environmental causes are generally simpler to model and understand.

6.1.1 Human and Organisational Errors

Human errors can be described as actions taken by individuals that can lead an activity (design, construction, and operation) to realise a quality lower than intended. Human errors also include actions *not* taken, as these also may lead an activity to realise a quality lower than intended. Many people typically think of human error as "operator error" or "cockpit error", in which the operator makes a slip or mistake due to misperceptions, faulty reasoning, inattention, or debilitating attributes such as sickness, drugs, or fatigue. However, there are many other important sources of human error. These includes factors such as management policies which pressure shipmasters to stay on schedule at all costs, poor equipment design which impedes the operator's ability to perform a task, improper or lack of maintenance, improper or lack of training, and inadequate number of crew to perform a task.

The human error factors range from those of judgement to ignorance, folly, and mischief. Inadequate training is the primary contributor to many of the past failures in marine structures. Also boredom has played a major role in many accidents. Based on a study by Bea [1] of human error factors in marine engineering the following primary factors were identified:

Inadequate training	Carelessness	Ego
Physical limitations	Wishful thinking	Laziness
Inadequate communication	Ignorance	Greed
Bad judgement	Negligence	Alcohol
Fatigue	Folly	Mischief
Boredom	Panic	Violations

---

[2] Some researchers even argue that 100% of all accidents are due to human error, since poor man-machine interface, failure of instrumentation (should have been checked more properly), under design, etc. all may be attributed as the result of some sort of human error. Any design is the consequence of human decisions.

Organisation errors are a departure from acceptable or desirable practice on the part of a group of individuals that results in unacceptable or undesirable results. Primary organisational error factors includes, [1]:

Ineffective regulatory requirements	Production orientation	Inequitable promotion / recognition
Poor planning / training	Cost-profit incentives	Ineffective monitoring
Poor communications	Time pressures	Ego
Low quality culture	Rejection of information	Negative incentives
Low worker morale	Complex structure	Violations

For example, the goals set by the organisation may lead rational individuals to conduct certain operations in manner that the corporate management would not approve if they were aware of their reliability implications. Similarly, corporate management, under pressures to reduce costs and maintain schedules, may not provide the necessary resources required allowing adequately safe operations.

Other types of organisation and management procedure that affect the system reliability include, for example, parallel processing such as developing design criteria at the same time as the structure is being designed – a procedure that may not be appropriate in economic terms according to the costs and uncertainties.

6.1.2 Human error evaluation

To date, four methodologies have been developed or adapted for maritime use. These are:

1. The operator function model (OFM) type of task analysis
2. Cognitive task analysis
3. Skill assessment
4. Error analysis

The OFM task analysis, developed in1986 by Mitchell and Miller, see Rasmussen [26], provides a breakdown of a function (such as avoiding collisions with neighbouring vessels) into the tasks that must be performed. This also includes the information needed to perform each task, and the decisions that direct the sequence of tasks. This type of task description is independent of the automation; that is, the same tasks, information, and decisions are required, regardless of whether they are performed by a human or by a machine. For example, in collision avoidance, other vessels must be detected, their relative motions analysed to determine whether there is a threat of collision, and a decision made regarding how to change own ship's course or speed in order to avoid a potential collision. These tasks must be performed regardless of who (human or machine) executes them.

The cognitive task analysis method extends the OFM by considering the mental demands that would be placed on a human operator while performing tasks. For example, in order for a human to detect a new ship as soon as it appears, vigilance (sustained attention) and discrimination (the ability to spot a target against the background) are required. The mental demands of analysing the relative motion of the target vessel include plotting a series of target ranges (distance) and bearings (its angular position relative to own ship) and evaluating the ratio of change over time. Hollnagel [14] introduced a task transaction vocabulary that categorises mental demands, such as “search”, “detect”, “code”, “interpret”, and “decide/select”. Assigning the appropriate OFM tasks to humans or machines can thereby represent different levels of automation. Then the cognitive impact of automation can be identified by comparing the number and types of cognitive demands placed on the human operator under the different levels of automation. For example, Froese *et al.* [4] found that when collision avoidance by manual methods was compared to the use of ARPA radar, then virtually all of the computational demands of the manual method had been eliminated through automation.

In order to evaluate the impact of automation on training requirements, a skill assessment technique was developed at US Coast Guard [30] by combining the OFM and cognitive task analyses with the Knowledge, Skills, and Abilities (KSA) analysis. The skill assessment is performed by taking each cognitive task (from the OFM/cognitive task analysis) and determining what types of knowledge or skill that is required for the proper performance of a task. The hybrid analysis thereby focuses the knowledge and skill assessment on the task level. For example, when comparing the manual task in collision avoidance of plotting target range and bearing to the automated scenario that displays target information on the ARPA, then the basic knowledge requirements of collision avoidance do not change with automation. However, the procedural requirements change radically. That is, the mariner has to understand the theory behind collision avoidance regardless of the level of automation, but the specific set of procedural knowledge and skills the mariner needs is dependent on the level and type of automation. Application of the described skill assessment technique has allowed both US Coast Guard [30] and Schraagen *et al.* [28] to distinguish changes in skill level as a result of automation.

The studies by Froese *et al.* [4] and by Scraagen *et al.* [28] concludes that the way an automated system is designed can also affect the mariner’s performance. Some automation “hides” information from the mariner, presenting only what the designer thought was needed. Unfortunately, many system designers do not fully understand the user’s task, and consequently we end up with less-than-perfect, error inducing designs. By studying the types of errors commonly made by operators, and by understanding the ramifications of these errors (i.e., are they just nuisance errors or can they cause an accident?), important information is gained that further can be used in training and system redesign. Both error analyses adopted in [4] and [28] consisted of interviewing mariners and instructors, and observing the use of automation during routine shipboard operations.

6.2 Aspects that the risk analysis should include

When considering a risk analysis aiming at estimating the causation probability system knowledge is important. First and most important – before system knowledge is applied – is a clear and unique definition of the purpose, extent and boundaries of the risk analysis. Having clearly formulated the purpose, extent and boundaries of the risk analysis, the subsequent subsections discuss aspects of the system knowledge that becomes relevant when formulating the risk model for estimating the causation probability. In broad terms the system knowledge relates to:

- Configuration of the considered navigational area
- Composition of the ship traffic in the area
- Environmental conditions, such as weather, visibility, current, etc.
- Configuration of considered vessel, such as main particulars, manoeuvrability, bridge layout and procedures.

Today, many ships have periodically unmanned engine rooms connected by computerised alarm systems to the bridge. Further, microcomputers for accounting, general record-keeping, and e-mail to land-based operations, automated satellite positioning systems (e.g., the global positioning system or GPS), navigation and collision-avoidance systems like electronic charts (ECDIS) and automated radar plotting aids (ARPA). With this boom in technology comes the concern that not all mariners understand how to use the automation effectively and safely. Indeed, there have been several “automation-assisted” accidents in recent years in which otherwise experienced mariners either did not know how to use the automated system or had trouble using it because of poor system design, Rothblum and Carvalhais [27]. The related human error modelling is best analysed using the cognitive task analysis. In a subsequent subsection the technical aspects of the different electronic systems is described.

6.2.1 Configuration of navigational area

System knowledge of the configuration of the navigational area concerns the arrangement of the route in the vicinity of the considered area and identification of all difficulties in following the route before the considered location. Routes in the considered region that crosses the route prior to the considered location may have influence on the navigational safety and may thus indirectly have influence on faults at the considered location.

The navigational markings, such as type of buoys that constitutes the routing system, must be identified. Further, presence and configuration of VTS system in the area as well as requirements for having pilot on board is part of the routing system. The purpose of the routing system is to improve the safety of navigation in converging areas and in areas where the density of traffic is great or where freedom of movement of shipping is inhibited by restricted sea-room, the existence of obstructions to navigation, limited depths and unfavourable meteorological conditions. This subsection describes some relevant aspects of the routing system.

Navigational route, markings, aids, and restrictions
Traffic lane - An area within defined limits in which one-way traffic is established. Natural obstacles, including those forming separation zones, may constitute a boundary.

Traffic Separation Scheme - A routing measure aimed at the separation of opposing streams of traffic by appropriate means and by establishment of traffic lanes.

Separation zone and lines - A zone or line separating the traffic lanes in which ships are proceeding in opposite or nearly opposite directions; or separating a traffic lane from the adjacent sea area; or separating traffic lanes designated for particular classes of ship proceeding in the same direction.

Inshore traffic zone - A routing measure comprising a designated area between the landward boundary of a traffic separation scheme and the adjacent coast, to be used in accordance with the provision of amendment to International Regulations for Preventing Collision at Sea, 1972 (Collision Regulations).

Deep-water route - A route within defined limits that have been accurately surveyed for clearance of sea bottom and submerged obstacles as indicated on the charts.

Precautionary areas - A routing measure comprising an area within defined limits where ships must navigate with particular caution and within which the direction of traffic flow may be recommended.

Navigational complications

Complications that may impinge on the operational safety, e.g. bridges, multiple routes, crossing traffic, etc.

Local and regional bathymetry

Have an influence on the vessel sizes that are able to operate in the area – or collide with specific obstacles. The distance from the route to the ground affects P_c for both collision and grounding.

VTS system

A VTS system is typically present in areas of high navigational complexity where an accurate monitoring or guidance of the vessels in the area is of importance. Typical such areas may be near location of large bridges, areas with high rate of icebergs, or highly trafficked areas. The main effect of a VTS system, for a ship in contact with the VTS system, will be on the selection of route and distribution of ships across the routes. Reportedly, Olsen *et al.* [22] found that the effect of the presence of a VTS system might reduce the causation probability for ship-bridge collisions by a factor of 2 to 3.

VTS systems may consist of the following equipment in different configurations, Olsen *et al.* [22]:

- Radar installations
- VHF radio and VHF direction finder
- Closed Circuit Television
- Infrared Television
- Presence of a guard ship

A VTS system consisting of only radar, VHF radio and VHF direction finder constitutes the basic system. Closed Circuit Television and Infrared Television are additional equipment. In some areas a guard ship may be attached to the VTS system.

Ships participating in the VTS system must – if mandatory when entering the VTS area – report to the VTS centre via the VHF radio. Local authorities define the requirement to the ship sizes that should participate in the VTS system. According to the IMO regulation it is mandatory for vessels above 300 GRT to have VHF radio onboard.

Some of the benefits of a VTS system is that the radar can detect navigational errors and thereby be corrected via the VHF communication. For ships violating the navigational regulations for the area, attempts can be made to establish contact with these over the VHF radio. Presence of Closed Circuit Television or Infrared Television allows for an improved surveillance of the navigation in the approach channels, for instance detecting a ship that omits to turn at a sea buoy or navigates of the channel. Presence of a guard ship may be able to help wandering vessels or like. This, of course, is highly dependent on the location of the guard ship and on the weather conditions.

The degree of vessel participating in the VTS system varies considerably for different locations and is highly dependent on the presence of identifiable hazards in the waterway (e.g. fishing boats, icebergs, bridges, etc.). Presence of identifiable hazards increases the degree of participation. It should be noted that ship owners might obtain lower insurance premiums if their vessels participate in local VTS systems. This aspect therefore presents incitement to participate in the VTS system. The following probabilities of a vessel *not* participating in the VTS system have been extracted from [22].

Participation conditions	**Probability of *not* participating**	**Reported by**
Mandatory	$1 \cdot 10^{-4}$	Japanese studies
Mandatory in domestic waters	$1 \cdot 10^{-3}$	Canadian Coast Guard
Voluntary in domestic waters	0.01 to 0.4	U.S. Coast Guard
Voluntary in the Dover Strait	0.2	U.K. Department of Transport

Moreover, in the event of a vessel not reporting to the VTS system, then almost all (>99%, [22]) vessels respond to a direct call if the VTS system broadcast position, speed and course of the vessel. Some vessels, however, have proved impossible to contact by VHF or from a guard ship.

When receiving an advice by VHF from the VTS centre, Olsen *et al.* [22] also reports that an average of 90% to 95% comply with the VTS advice. It is noted that the compliance is dependent on the nature of the advice and on the credibility of the system with the mariner. Local conditions near the vessel and unknown to the VTS may prevent the ship operator from following the advice.

Requirements for pilot on board

In some navigational areas it is required that vessels above a specific size must take a pilot on board. Aspect that must be addressed relates to how well does the pilot inform the master of the vessel of navigational plans? What are standard procedures? Are there requirements to the pilot of specific knowledge of the manoeuvrability of the vessel? Etc.

6.2.2 Composition of ship traffic

The vessels that operate at general international routes range from traditional sailing ships, leisure crafts and fishing vessels (whose courses are unpredictable) to large tankers that are confined to deep-water routes only. The large diversity in the vessel traffic composition must be taken properly into account. This concerns bulk carriers and tankers in ballast having poor manoeuvrability; container ships with high cruising speed, hard pressed to arrive at their designated terminals just in time. Smaller petroleum, chemical and gas tankers feeding depots around the region, tow-boats and barges requiring plenty of sea-room to manoeuvre, and passenger ferries crossing the considered operational route.

Among the shipmasters of these vessels there is a wide variance in the interpretation of safety and the choice of accepting a particular standard, which varies from criteria used, the circumstances and in most cases opinion.

In gathering information on the ship traffic, focus will normally be on the commercial traffic, since these always will represent the primary threat to the navigational area. Leisure traffic and local fishing activity, however, can disturb the commercial traffic and thus be a source of errors. The extent and pattern of this type of traffic should be quantified. Type, size, and frequency of vessels operating in the area should be registered. When combined with information of the configuration of the navigational area this information provides guidance of the possibility for performing evasive manoeuvres. In essence, more ships mean more risks!

For long-term design purposes forecasting of traffic intensity and composition is important. In this respect local bathymetry provides guidance for limiting vessel sizes, at least with respect to draft.

6.2.3 Environmental conditions

The annual conditions for

- Weather condition,
- wind variations, cross wind and in sailing direction
- waves,
- visibility (fog, precipitation)
- current variations, cross current and in sailing direction
- ice conditions

Major parts of these aspects were addressed in Friis Hansen and Pedersen [10].

6.2.4 Configuration of considered vessel

Aspects that should be described

- Vessel type and particulars: speed, profile.
- Manoeuvrability of considered vessel
- Layout of Man-Machine interface
- Number of officers on the bridge
- Instrumentation: ARPA, ECDIS, GPS, collision avoidance, and track keeping, etc.

In the last few years, the Electronic Chart Display and Information System (ECDIS) has emerged as a powerful addition to the modern bridge. ECDIS offers the possibility for major changes in the navigation process and improves the safety and efficiency of maritime operations. By superimposing three items: a chart, the ship's real-time position, and radar on one display, ECDIS has the potential to improve the accuracy of navigation, increase awareness of dangerous conditions, and reduce the mariner's workload. At US Coast Guard, [30], the potential effects of these systems on bridge operations were examined, using the controlled conditions possible on a full-mission simulator. Four issues were examined: the potential of ECDIS to contribute to navigational precision, its potential to reduce navigation workload, the chart features and navigation functions required by the mariner, and the potential contribution of the integration of radar features on ECDIS. The results provided support to the U.S. position on the International Maritime Organization's (IMO) Standards for ECDIS and recommendations for future system design and for the incorporation of the system in bridge operations, [30].

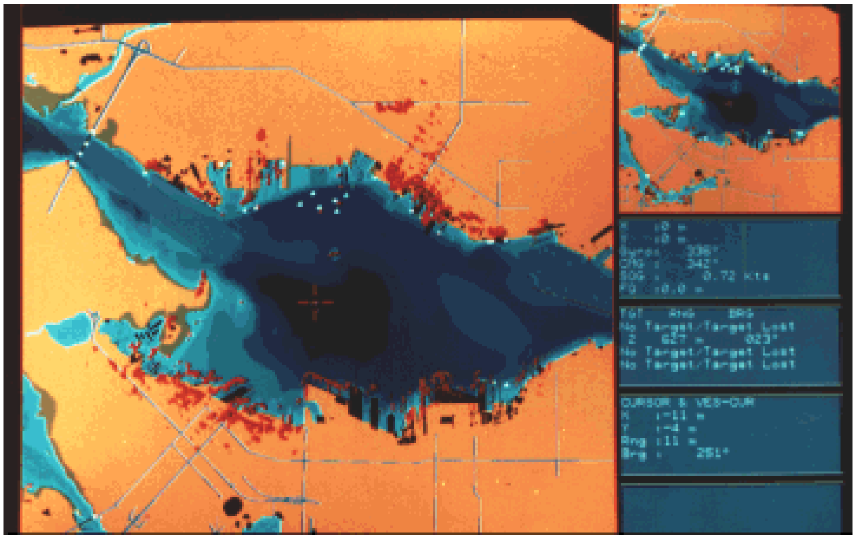


Figure 16 Illustration of an ECDIS display, from [30].

Other relevant concerns relates to:

- Navigational procedures and practice: voyage planning, pre-planning of actions and procedures in the event of evasive manoeuvres. Communication on the bridge
- Human failures:
  - no action: absence, present but not attentive, attentive but problem not realised
  - Unintended wrong action: situation misunderstood, wrong action chosen, communication problems
  - Intended wrong action: navigational basis (charts) not updated, confusions of buoys and/or landmarks, manoeuvring capabilities overestimated, clearance requirements underestimated (relevant for ship-bridge collisions)
- Technical failures:
  - loss of propulsion
  - steering system failures
  - radar failure
  - GPS failure

Influence of the effects of automation (ARPA and ECDIS) on navigational functions: voyage planning, collision avoidance, and track keeping. What is the management attitude towards level of detail in voyage planning? Concerns should also be given on how training may affect the situation? Changes in training: less on computation and more on interpretation is needed given the wide usage of ARPA.

At USCG [30] the skills assessment and error analysis techniques identified several important types of skill and knowledge that were not fully covered in current internationally recommended training course objectives for ARPA. These same techniques also allowed the development of training course objectives for ECDIS, a relatively new piece of equipment for which no formal training courses exists.

In Froese *et al.* [4] and in Schraagen *et al.* [28] the cognitive task analysis and error analysis also proved valuable in identifying aspects of the user interface and equipment functionality which were inconsistent with the needs of the crew in the performance of the automated tasks. Taken together, these tools provide a powerful and comprehensive method of identifying the impact of automation on task and training requirements.

7. SHIP TYPES USED IN THE GRISK PROGRAM

The GRISK-program uses internally the following 14 ship types

GRISK Shiptype	Ship Code	
Crude oil tanker	1	This seems as a large and homogenous group
Oil products tanker	2	This is chosen because the oil products carried by this type, has different properties than crude oil.
Chemical tanker	3	Chemical tankers have generally more separate tanks than other tankers. They carry chemicals which in many cases are dissolved in the ocean when spilled. This is why marginal types such as wine and juice tanks are included here.
Gas tanker	4	Present a different risk (explosion) than oil and chemical tankers
Container ship	5	Often fast ships. It could be categorized as just cargo
General cargo ship	6	Often older and slower ships. It could be categorized as just cargo
Bulk carrier	7	This seems as a large and homogenous group
Ro-Ro cargo ship	8	This could also be classified as just cargo. It has been chosen because of its special stability problems
Passenger ship	9	All ships carrying more than 12 passengers sailing less than 30 knots
Fast ferry	10	All passenger ships sailing faster than 30 knots. Lloyds do not have a category for this
Support ship	11	A large group consisting mainly of small and slow work related crafts. However it also includes supply ships, tugs and pilots. They typical sail more randomly than larger ships
Fishing ship	12	Most fishing ships do not carry an AIS transponder but from a collision analysis point of view there present could be important. There is of course also the question of whether the ship is fishing or just sailing. This I believe is included in the activity part of the AIS data
Other ship	13	All other. Includes naval ships
Pleasure boat	14	Is not relevant for AIS, but from a collision analysis point of view they would be nice to include.

8. CONCLUSION

A complete procedure has been presented for the analysis of grounding and ship-ship collision rates and the associated damage caused by collisions. The procedure has been applied to analysis of grounding and collision risks for selected geographical areas (Sea of Aaland and Bornholms Gat / Baltic West). These studies have not yet been reported, but reference will be added when these reports are completed.

The document also presents a risk-based framework for calculating the causation probability for grounding and collision. The causation factor for ship-ship collision has been calculated using a Bayesian Network model. The result of the analysis was compared to reported causation probabilities and surprisingly good agreement was obtained. In order to be fully complete, however, the modelling needs to be extended. The concern that needs to be addressed was also described in the present document.

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Appendix: Used ship types compared to the types defined in the Lloyds data base

The GRISK-program uses internally the following 14 ship types

GRISK Shiptype	**Ship Code**	
Crude oil tanker	1	This seems as a large and homogenous group
Oil products tanker	2	This is chosen because the oil products carried by this type, has different properties than crude oil.
Chemical tanker	3	Chemical tankers have generally more separate tanks than other tankers. They carry chemicals which in many cases are dissolved in the ocean when spilled. This is why marginal types such as wine and juice tanks are included here.
Gas tanker	4	Present a different risk (explosion) than oil and chemical tankers
Container ship	5	Often fast ships. It could be categorized as just cargo
General cargo ship	6	Often older and slower ships. It could be categorized as just cargo
Bulk carrier	7	This seems as a large and homogenous group
Ro-Ro cargo ship	8	This could also be classified as just cargo. It has been chosen because of its special stability problems
Passenger ship	9	All ships carrying more than 12 passengers sailing less than 30 knots
Fast ferry	10	All passenger ships sailing faster than 30 knots. Lloyds do not have a category for this
Support ship	11	A large group consisting mainly of small and slow work related crafts. However it also includes supply ships, tugs and pilots. They typical sail more randomly than larger ships
Fishing ship	12	Most fishing ships do not carry an AIS transponder but from a collision analysis point of view there present could be important. There is of course also the question of whether the ship is fishing or just sailing. This I believe is included in the activity part of the AIS data
Other ship	13	All other. Includes naval ships
Pleasure boat	14	Is not relevant for AIS, but from a collision analysis point of view they would be nice to include.

Dimensions of the ship types calculated from Lloyd's ship database

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V) Knots	Bulb pct
Crude oil tanker	1	-1-425	1971	245	5.68	1.96	1.42	0.67	14.8	0.98
	1	0-25								
	1	25-50	6	40	5.12	2.40	1.10	0.12		
N=Number of ships	1	50-75	26	65	5.87	2.29	1.14	0.20	11.3	0.89
E() = average	1	75-100	40	89	6.26	2.04	1.16	0.20	12.4	0.88
L=Lpp=perpendicular	1	100-125	7	117	6.94	2.23	1.52	0.84	12.1	1.00
B=Breadth moulded	1	125-150	16	140	6.33	2.10	1.37	0.64	13.9	0.30
D=Depth	1	150-175	154	169	5.63	1.79	1.49	0.67	14.4	0.99
T=Draught	1	175-200	50	184	6.01	1.81	1.44	0.58	14.6	0.96
Cb=Block coefficient	1	200-225	221	218	6.28	1.80	1.45	0.70	14.5	0.97
V=Speed	1	225-250	611	234	5.61	2.02	1.45	0.70	14.7	1.00
Ships are from 1980-	1	250-275	336	262	5.60	2.01	1.41	0.72	14.9	1.00
	1	275-300	7	284	5.95	2.00	1.36	0.59	14.9	1.00
	1	300-325	478	317	5.43	1.96	1.42	0.66	15.4	0.96
	1	325-350	15	328	5.81	1.84	1.40	0.77	14.7	1.00
	1	350-375	4	366	5.38	2.19	1.29	0.83	16.1	1.00
	1	375-400								
	1	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Oil products tanker	2	-1-425	5207	115	5.87	2.03	1.32	0.42	13.2	0.84
	2	0-25	122	24	3.43	2.31	1.25		11.2	0.44
	2	25-50	477	39	4.81	2.45	1.15	0.17	9.6	0.30
	2	50-75	900	65	5.72	2.32	1.17	0.19	11.2	0.58
	2	75-100	1079	89	5.97	2.03	1.25	0.32	12.7	0.89
	2	100-125	738	111	6.24	2.00	1.33	0.46	13.1	0.85
	2	125-150	391	137	6.42	1.96	1.38	0.56	13.8	0.82
	2	150-175	968	169	5.67	1.79	1.49	0.63	14.7	0.98
	2	175-200	283	178	5.97	1.77	1.47	0.61	14.9	0.77
	2	200-225	178	218	6.70	1.62	1.46	0.70	14.9	1.00
	2	225-250	68	235	5.65	1.97	1.48	0.63	14.9	0.98
	2	250-275	2	264	5.28	2.16	1.40	0.85	15.6	1.00
	2	275-300	1	279	6.27	1.87	1.82	0.94	15.0	
	2	300-325								
	2	325-350								
	2	350-375								
	2	375-400								
	2	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Chemical tanker	3	-1-425	1281	86	6.10	2.14	1.25	0.33	12.6	0.68
	3	0-25	65	20	3.57	2.41	1.32		11.3	0.29
	3	25-50	267	42	5.15	2.31	1.13	0.21	9.7	0.30
	3	50-75	326	61	5.85	2.22	1.12	0.29	11.4	0.57
	3	75-100	207	86	6.40	2.12	1.30	0.33	12.5	0.77
	3	100-125	204	110	7.28	2.02	1.38	0.34	13.4	0.67
	3	125-150	117	135	6.48	1.93	1.36	0.47	14.6	0.93
	3	150-175	83	164	5.84	1.89	1.42	0.51	15.1	1.00
	3	175-200	11	182	5.67	1.97	1.47	0.64	16.8	1.00
	3	200-225								
	3	225-250	1	232	5.52	1.98	1.45	0.82	15.4	1.00
	3	250-275								
	3	275-300								
	3	300-325								
	3	325-350								
	3	350-375								
	3	375-400								
	3	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Gas tanker	4	-1-425	1037	139	5.82	1.95	1.56	0.41	15.1	0.92
	4	0-25	3			2.13	1.74		12.2	1.00
	4	25-50	21	44	4.63	2.83	1.31	0.18	10.2	0.80
	4	50-75	211	63	5.36	2.21	1.23	0.23	12.2	0.82
	4	75-100	261	90	5.74	2.12	1.37	0.40	13.3	0.94
	4	100-125	131	110	6.14	1.83	1.40	0.44	14.9	0.90
	4	125-150	55	142	6.14	1.66	1.55	0.56	16.0	0.82
	4	150-175	56	163	6.02	1.57	1.66	0.58	16.2	1.00
	4	175-200	11	191	6.17	1.60	1.73	0.66	16.4	1.00
	4	200-225	107	215	6.01	1.73	1.81	0.57	16.6	0.93
	4	225-250	3	230	5.99	1.51	2.22	0.47	17.7	1.00
	4	250-275	129	268	6.07	1.72	2.17	0.44	19.7	1.00
	4	275-300	49	278	6.04	1.78	2.22	0.32	19.6	1.00
	4	300-325								
	4	325-350								
	4	350-375								
	4	375-400								
	4	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Container ship	5	-1-425	4678	176	6.48	1.84	1.48	0.27	19.8	0.99
	5	0-25	101	23	3.47	1.76	1.54	0.26	22.2	1.00
	5	25-50	25	40	4.83	2.06	1.35	0.11	11.5	
	5	50-75	94	65	5.43	2.25	1.36	0.10	12.5	0.85
	5	75-100	370	89	5.67	2.08	1.37	0.24	14.2	0.96
	5	100-125	615	114	6.01	1.93	1.37	0.26	16.3	0.99
	5	125-150	886	137	6.17	1.89	1.41	0.26	18.6	0.99
	5	150-175	669	162	6.09	1.89	1.44	0.31	19.0	1.00
	5	175-200	517	190	6.34	1.80	1.50	0.21	20.8	1.00
	5	200-225	249	212	6.76	1.75	1.52	0.27	21.4	1.00
	5	225-250	264	237	7.37	1.68	1.59	0.32	22.6	1.00
	5	250-275	409	263	7.33	1.62	1.69	0.28	24.3	1.00
	5	275-300	327	283	8.09	1.58	1.66	0.32	24.4	1.00
	5	300-325	105	315	7.29	1.76	1.72	0.18	25.0	1.00
	5	325-350	36	333	7.78	1.71	1.71	0.50	25.0	1.00
	5	350-375	10	361	7.58	1.81	1.72	0.66	25.0	1.00
	5	375-400	1	376	6.67	1.87	1.89	0.63	25.0	1.00
	5	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
General cargo ship	6	-1-425	9457	87	5.89	2.03	1.40	0.22	12.5	0.80
	6	0-25	413	21	3.11	2.29	1.38	0.13	11.3	0.56
	6	25-50	1101	41	4.88	2.19	1.38	0.12	10.0	0.64
	6	50-75	2690	63	5.62	2.02	1.46	0.10	11.0	0.82
	6	75-100	2894	87	5.95	2.00	1.35	0.25	12.3	0.79
	6	100-125	1180	110	6.55	2.07	1.39	0.34	13.3	0.69
	6	125-150	668	138	6.73	1.94	1.40	0.36	14.8	0.83
	6	150-175	300	161	6.35	1.80	1.41	0.33	15.6	0.99
	6	175-200	208	183	6.20	1.79	1.42	0.31	15.7	0.98
	6	200-225	2	202	6.53	1.75	1.51	0.76	15.8	1.00
	6	225-250	1	237	7.35	1.76	1.55	0.67	20.5	
	6	250-275								
	6	275-300								
	6	300-325								
	6	325-350								
	6	350-375								
	6	375-400								
	6	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Bulk carrier	7	-1-425	6090	185	6.14	1.87	1.41	0.30	14.1	0.96
	7	0-25	63			2.18	1.35		13.5	0.80
	7	25-50	160	44	4.07	2.46	1.41	0.19	10.1	0.64
	7	50-75	263	62	4.92	2.13	1.42	0.18	10.9	0.78
	7	75-100	121	88	5.54	2.19	1.35	0.27	12.1	0.75
	7	100-125	212	111	6.22	1.98	1.37	0.32	13.1	0.77
	7	125-150	396	141	5.91	1.91	1.39	0.20	13.9	0.96
	7	150-175	1032	165	6.22	1.88	1.41	0.27	14.3	0.98
	7	175-200	1556	182	6.03	1.83	1.45	0.27	14.4	0.99
	7	200-225	1376	216	6.70	1.72	1.40	0.33	14.5	0.98
	7	225-250	174	235	6.57	1.90	1.43	0.45	14.3	0.89
	7	250-275	255	262	6.02	1.85	1.38	0.53	14.2	0.98
	7	275-300	431	281	6.12	1.89	1.36	0.32	14.6	0.99
	7	300-325	47	307	6.16	2.02	1.40	0.39	13.9	1.00
	7	325-350	4	327	5.64	1.87	1.39	0.63	13.8	1.00
	7	350-375								
	7	375-400								
	7	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Ro-Ro cargo ship	8	-1-425	1161	123	5.24	2.42	1.91	0.16	16.7	0.87
	8	0-25	47	22	3.23	3.38	1.63	0.18	10.4	0.09
	8	25-50	292	40	4.11	3.57	1.35	0.05	9.5	
	8	50-75	137	58	4.52	3.63	1.44	0.10	9.9	0.23
	8	75-100	61	90	5.13	2.28	1.67	0.23	14.5	0.93
	8	100-125	58	111	5.71	2.23	1.66	0.23	16.5	1.00
	8	125-150	60	141	6.00	2.05	1.90	0.18	18.1	0.96
	8	150-175	228	166	5.55	1.82	2.21	0.21	18.8	0.99
	8	175-200	257	188	5.93	1.58	2.43	0.20	19.3	1.00
	8	200-225	12	216	6.70	1.38	2.60	0.25	20.2	1.00
	8	225-250	9	236	7.31	1.79	1.56	0.48	20.0	0.88
	8	250-275								
	8	275-300								
	8	300-325								
	8	325-350								
	8	350-375								
	8	375-400								
	8	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Passenger ship	9	-1-425	2999	80	4.78	2.72	1.81	0.16	17.9	0.61
	9	0-25	489	22	2.96	2.90	1.83	0.09	18.5	0.11
	9	25-50	1134	35	3.93	2.95	1.76	0.09	16.8	0.19
	9	50-75	406	61	4.59	3.00	1.64	0.15	14.1	0.53
	9	75-100	225	86	5.21	2.60	1.83	0.19	15.5	0.56
	9	100-125	147	112	5.76	2.27	1.82	0.27	18.0	0.81
	9	125-150	190	136	5.89	2.12	2.02	0.27	19.8	0.95
	9	150-175	175	162	6.26	2.37	1.89	0.25	21.6	0.95
	9	175-200	122	184	6.73	2.09	2.05	0.22	23.4	0.99
	9	200-225	38	215	6.89	2.09	2.28	0.23	20.8	1.00
	9	225-250	33	238	6.96	2.54	1.82	0.31	21.6	1.00
	9	250-275	36	263	8.01	2.33	2.10	0.26	22.9	1.00
	9	275-300	1	275	7.13	3.30	1.33		22.1	1.00
	9	300-325	3	303	7.69	2.64	1.90		24.5	1.00
	9	325-350								
	9	350-375								
	9	375-400								
	9	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Fast ferry	10	-1-425	530	47	3.67	3.00	2.38	0.08	36.2	0.16
	10	0-25	92	24	2.82	3.00	1.99	0.03	36.5	0.02
	10	25-50	319	35	3.57	2.88	2.44	0.08	35.5	0.16
	10	50-75	54	65	3.35	3.71	2.26	0.05	37.3	0.24
	10	75-100	48	86	4.45	3.14	2.57	0.08	38.2	0.22
	10	100-125	8	112	4.94	2.76	2.77	0.12	38.9	0.43
	10	125-150	6	128	5.57	2.22	2.73	0.08	40.5	
	10	150-175								
	10	175-200	1	191	7.24	1.68	2.15	0.58	32.0	1.00
	10	200-225	2	208	8.00	1.40	2.51		30.5	1.00
	10	225-250								
	10	250-275								
	10	275-300								
	10	300-325								
	10	325-350								
	10	350-375								
	10	375-400								
	10	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Support ship	11	-1-425	12006	42	3.63	2.32	1.33	0.19	13.0	0.13
	11	0-25	3292	22	2.94	2.27	1.35	0.37	12.4	0.02
	11	25-50	5671	32	3.39	2.28	1.33	0.12	13.1	0.05
	11	50-75	2293	60	4.34	2.45	1.28	0.15	13.0	0.28
	11	75-100	450	83	4.68	2.41	1.34	0.22	13.9	0.46
	11	100-125	129	112	5.25	2.30	1.53	0.22	13.7	0.60
	11	125-150	52	134	5.25	2.29	1.57	0.32	14.7	0.52
	11	150-175	23	160	5.44	2.46	1.49	0.20	14.8	0.47
	11	175-200	8	189	5.79	1.86	1.61	0.42	12.3	0.80
	11	200-225	25	213	5.74	1.93	1.48	0.40	12.7	0.82
	11	225-250	34	235	5.59	1.89	1.46	0.49	13.3	0.75
	11	250-275	11	263	5.64	1.86	1.45	0.37	13.4	1.00
	11	275-300	8	284	5.23	1.97	1.39	0.34	14.5	0.33
	11	300-325	7	308	5.46	1.95	1.38	0.41	14.5	1.00
	11	325-350	3	329	5.29	2.05	1.33	0.82	15.1	1.00
	11	350-375								
	11	375-400								
	11	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Fishing ship	12	-1-425	8384	40	4.27	1.95	1.31	0.20	11.8	0.71
	12	0-25	3009	22	3.16	2.00	1.27	0.16	10.2	0.39
	12	25-50	3928	37	4.37	2.00	1.27	0.19	11.7	0.84
	12	50-75	1109	56	4.93	1.80	1.38	0.25	13.6	0.74
	12	75-100	267	89	5.76	1.66	1.65	0.40	14.8	0.55
	12	100-125	64	108	5.90	1.65	1.68	0.42	15.2	0.69
	12	125-150	3	132	6.37	1.93	1.49	0.25	15.8	
	12	150-175	4	165	6.11	2.23	1.58	0.72	14.6	0.25
	12	175-200								
	12	200-225								
	12	225-250								
	12	250-275								
	12	275-300								
	12	300-325								
	12	325-350								
	12	350-375								
	12	375-400								
	12	400-425								

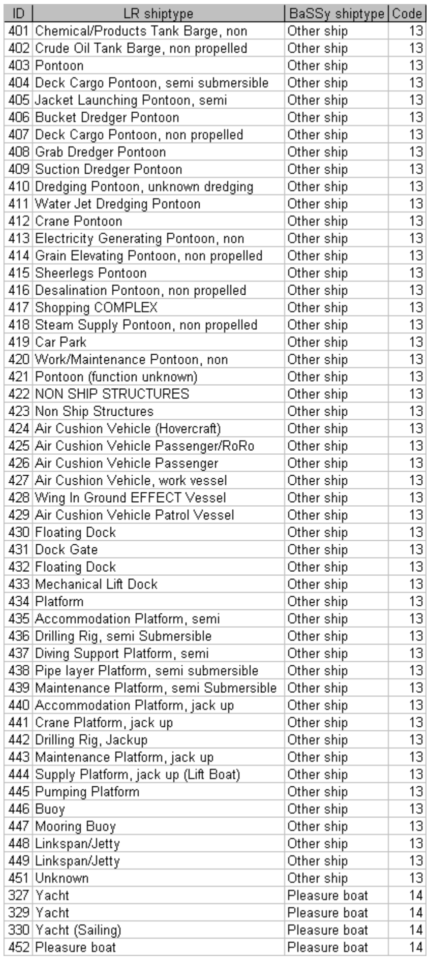
Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Other ship	13	-1-425	2047	69	4.05	3.06	1.61	0.16	15.4	0.44
	13	0-25	585	21	3.09	3.40	1.81	0.15	22.0	0.11
	13	25-50	502	36	3.59	3.12	1.52	0.21	14.2	0.39
	13	50-75	383	61	4.19	2.91	1.48	0.13	13.3	0.58
	13	75-100	281	86	4.10	3.05	1.60	0.13	15.0	0.54
	13	100-125	145	111	4.35	3.14	1.81	0.13	16.2	0.44
	13	125-150	53	136	5.52	2.57	1.39	0.08	13.8	0.50
	13	150-175	34	164	5.22	2.47	1.99	0.32	15.4	1.00
	13	175-200	37	188	6.23	1.94	1.62	0.25	18.4	1.00
	13	200-225	15	215	5.75	2.64	1.62	0.46	14.3	0.67
	13	225-250	4	239	4.60	2.79	2.67	0.31		
	13	250-275	2	257	4.28	2.00	1.43			
	13	275-300	1	294	4.74	1.93	1.46			
	13	300-325								
	13	325-350								
	13	350-375								
	13	375-400								
	13	400-425								

Ship Type	Ship Code	Lpp [a;b[	Ntotal	E(L)	E(L/B)	E(B/D)	E(D/T)	E(Cb)	E(V)	Bulb pct
Pleasure boat	14	-1-425	786	39	4.34	1.94	1.84	0.14	16.6	0.34
	14	0-25	143	19	3.25	1.87	1.98	0.03	18.4	
	14	25-50	536	36	4.33	1.95	1.83	0.14	16.2	0.26
	14	50-75	88	58	4.97	1.90	1.74	0.25	17.0	0.62
	14	75-100	14	85	5.67	2.22	1.60	0.10	18.9	0.80
	14	100-125	2	107	6.24	2.45	1.66	0.34	19.8	1.00
	14	125-150	3	132	6.77	2.03	2.03	0.19	25.0	
	14	150-175								
	14	175-200								
	14	200-225								
	14	225-250								
	14	250-275								
	14	275-300								
	14	300-325								
	14	325-350								
	14	350-375								
	14	375-400								
	14	400-425								

ID	LR shiptype	BaSSy shiptype	Code
27	Oil	Crude oil tanker	1
28	Crude Oil Tanker	Crude oil tanker	1
29	Shuttle Tanker	Crude oil tanker	1
30	Crude Oil Tanker	Crude oil tanker	1
31	Crude/Oil Products Tanker	Crude oil tanker	1
13	Chemical/Oil Products Tanker	Oil products tanker	2
14	Chemical/Products Tanker	Oil products tanker	2
32	Oil Products Tanker	Oil products tanker	2
33	Products Tanker	Oil products tanker	2
34	Tanker (unspecified)	Oil products tanker	2
35	Bitumen Tanker	Oil products tanker	2
36	Asphalt/Bitumen Tanker	Oil products tanker	2
37	Coal/Oil Mixture Tanker	Oil products tanker	2
38	Coal/Oil Mixture Tanker	Oil products tanker	2
284	Bunkering Tanker	Oil products tanker	2
285	Bunkering Tanker	Oil products tanker	2
290	Inland Waterways Tanker	Oil products tanker	2
293	Chemical/Products Tanker, Inland Waterways	Oil products tanker	2
294	Inland Waterways Oil Tanker	Oil products tanker	2
295	Oil Tanker, Inland Waterways	Oil products tanker	2
6	LPG/Chemical Tanker	Chemical tanker	3
9	Chemical	Chemical tanker	3
10	Chemical Tanker	Chemical tanker	3
11	Molten Sulphur Tanker	Chemical tanker	3
12	Chemical Tanker	Chemical tanker	3
15	Wine Tanker	Chemical tanker	3
16	Wine Tanker	Chemical tanker	3
17	Vegetable Oil Tanker	Chemical tanker	3
18	Vegetable Oil Tanker	Chemical tanker	3
19	Edible Oil Tanker	Chemical tanker	3
20	Edible Oil Tanker	Chemical tanker	3
21	Beer Tanker	Chemical tanker	3
22	Beer Tanker	Chemical tanker	3
23	Latex Tanker	Chemical tanker	3
24	Latex Tanker	Chemical tanker	3
25	Fruit Juice Tanker	Chemical tanker	3
26	Fruit Juice Tanker	Chemical tanker	3
39	Other Liquids	Chemical tanker	3
40	Water Tanker	Chemical tanker	3
41	Water Tanker	Chemical tanker	3
42	Molasses Tanker	Chemical tanker	3
43	Molasses Tanker	Chemical tanker	3
44	Glue Tanker	Chemical tanker	3
45	Glue Tanker	Chemical tanker	3
46	Alcohol Tanker	Chemical tanker	3
47	Alcohol Tanker	Chemical tanker	3
48	Caprolactam Tanker	Chemical tanker	3
49	Caprolactam Tanker	Chemical tanker	3
291	Inland Waterways Chemical Tanker	Chemical tanker	3
292	Chemical Tanker, Inland Waterways	Chemical tanker	3
296	Inland Waterways Other Liquids Tanker	Chemical tanker	3
297	Edible Oil Tanker, Inland Waterways	Chemical tanker	3
298	Water Tanker, Inland Waterways	Chemical tanker	3
299	Vegetable Oil Tanker, Inland Waterways	Chemical tanker	3
1	Liquefied Gas	Gas tanker	4
2	LNG Tanker	Gas tanker	4
3	LNG Tanker	Gas tanker	4
4	LPG Tanker	Gas tanker	4
5	LPG Tanker	Gas tanker	4
7	CN2 Tanker	Gas tanker	4
8	CN2 Tanker	Gas tanker	4
95	Container	Container ship	5
96	Container Ship	Container ship	5
97	Container Ship (Fully Cellular)	Container ship	5
98	Container Ship (Fully Cellular with RoRo	Container ship	5
101	Refrigerated Cargo	Container ship	5
102	Refrigerated Cargo Ship	Container ship	5
103	Refrigerated Cargo Ship	Container ship	5
134	Nuclear Fuel Carrier	Container ship	5
135	Nuclear Fuel Carrier	Container ship	5
136	Nuclear Fuel Carrier (with RoRo facility)	Container ship	5
303	Container Ship (Fully Cellular), Inland	Container ship	5
81	General Cargo	General cargo ship	6
82	General Cargo Ship	General cargo ship	6
83	General Cargo Ship (with RoRo facility)	General cargo ship	6
84	Open Hatch Cargo Ship	General cargo ship	6
85	General Cargo/Tanker (Container/oil/bulk COB	General cargo ship	6
86	General Cargo/Tanker	General cargo ship	6
87	General Cargo Ship	General cargo ship	6
88	Palletised Cargo Ship	General cargo ship	6
89	Palletised Cargo Ship	General cargo ship	6
90	Deck Cargo Ship	General cargo ship	6
91	Deck Cargo Ship	General cargo ship	6
125	Other Dry Cargo	General cargo ship	6
149	Fish Carrier	General cargo ship	6
150	Fish Carrier	General cargo ship	6
151	Live Fish Carrier	General cargo ship	6
152	Live Fish Carrier (Well Boat)	General cargo ship	6
301	Inland Waterways Dry Cargo	General cargo ship	6
304	General Cargo, Inland Waterways	General cargo ship	6
50	Bulk Dry	Bulk carrier	7
51	Bulk Carrier	Bulk carrier	7
52	Bulk Carrier	Bulk carrier	7
53	Bulk Carrier, Laker Only	Bulk carrier	7
54	Bulk Carrier (with Vehicle Decks)	Bulk carrier	7
55	Ore Carrier	Bulk carrier	7
56	Ore Carrier	Bulk carrier	7
57	Bulk Dry/Oil	Bulk carrier	7
58	Bulk/Oil Carrier	Bulk carrier	7
59	Bulk/Oil Carrier (OBO)	Bulk carrier	7
60	Ore/Oil Carrier	Bulk carrier	7
61	Ore/Oil Carrier	Bulk carrier	7
62	Self Discharging Bulk Dry	Bulk carrier	7
63	Self Discharging Bulk Carrier	Bulk carrier	7
64	Bulk Cargo Carrier, self discharging	Bulk carrier	7
65	Bulk Cargo Carrier, self discharging, Laker	Bulk carrier	7
66	Other Bulk Dry	Bulk carrier	7
67	Cement Carrier	Bulk carrier	7
68	Cement Carrier	Bulk carrier	7
69	Wood Chips Carrier	Bulk carrier	7
70	Wood Chips Carrier, self unloading	Bulk carrier	7
71	Urea Carrier	Bulk carrier	7
72	Urea Carrier	Bulk carrier	7
73	Aggregates Carrier	Bulk carrier	7
74	Aggregates Carrier	Bulk carrier	7
75	Limestone Carrier	Bulk carrier	7
76	Limestone Carrier	Bulk carrier	7
77	Refined Sugar Carrier	Bulk carrier	7
78	Refined Sugar Carrier	Bulk carrier	7
79	Powder Carrier	Bulk carrier	7
80	Powder Carrier	Bulk carrier	7
130	Heavy Load Carrier	Bulk carrier	7
131	Heavy Load Carrier	Bulk carrier	7
137	Pulp Carrier	Bulk carrier	7
138	Pulp Carrier	Bulk carrier	7
164	Pearl Shells Carrier	Bulk carrier	7
165	Pearl Shells Carrier	Bulk carrier	7
302	Bulk Cement Carrier, Inland Waterways	Bulk carrier	7
104	RoRo Cargo	RoRo cargo ship	8
105	RoRo Cargo Ship	RoRo cargo ship	8
106	RoRo Cargo Ship	RoRo cargo ship	8
107	Rail Vehicles Carrier	RoRo cargo ship	8
108	Vehicles Carrier	RoRo cargo ship	8
109	Vehicles Carrier	RoRo cargo ship	8
110	Container/RoRo Cargo Ship	RoRo cargo ship	8
111	Container/RoRo Cargo Ship	RoRo cargo ship	8
112	Landing Craft	RoRo cargo ship	8
113	Landing Craft	RoRo cargo ship	8
126	Livestock Carrier	RoRo cargo ship	8
127	Livestock Carrier	RoRo cargo ship	8
128	Barge Carrier	RoRo cargo ship	8
129	Barge Carrier	RoRo cargo ship	8
307	Inland Waterways RoRo Cargo	RoRo cargo ship	8
308	RoRo Cargo Ship, Inland Waterways	RoRo cargo ship	8
92	Passenger/General Cargo	Passenger ship	9
93	Passenger/General Cargo Ship	Passenger ship	9
94	General Cargo/Passenger Ship	Passenger ship	9
99	Passenger/Container Ship	Passenger ship	9
100	Passenger/Container Ship	Passenger ship	9
114	Passenger/RoRo Cargo	Passenger ship	9
115	Passenger/RoRo Cargo Ship	Passenger ship	9
116	Passenger/RoRo Ship (Vehicles)	Passenger ship	9
117	Passenger/RoRo Ship (Vehicles/Rail)	Passenger ship	9
118	Passenger/Landing Craft	Passenger ship	9
119	Passenger/Landing Craft	Passenger ship	9
120	Passenger	Passenger ship	9
121	Passenger (Cruise) Ship	Passenger ship	9
122	Passenger/Cruise	Passenger ship	9
123	Passenger Ship	Passenger ship	9
124	Passenger Ship	Passenger ship	9
263	Hospital Vessel	Passenger ship	9
264	Hospital Vessel	Passenger ship	9
300	Inland Waterways Dry Cargo/Passenger	Passenger ship	9
305	Inland Waterways Passenger/General Cargo	Passenger ship	9
306	General Cargo/Passenger Ship, Inland Waterways	Passenger ship	9
309	Inland Waterways Passenger/RoRo Cargo	Passenger ship	9
310	Passenger/RoRo Ship (Vehicles), Inland Waterways	Passenger ship	9
311	Passenger/RoRo Ship (Vehicles/Train), Inland	Passenger ship	9
312	Inland Waterways Passenger	Passenger ship	9
313	Cruise Ship, Inland Waterways	Passenger ship	9
314	Passenger Ship, Inland Waterways	Passenger ship	9
453	Passenger / Ro-Ro Cargo Ship	Passenger ship	9
454	Passenger/Ro-Ro Ship (Vehicles)	Passenger ship	9
450	Fast ferry	Fast ferry	10
153	Fishing Support Vessel	Support ship	11
154	Fish Farm Support Vessel	Support ship	11
155	Fishery Patrol Vessel	Support ship	11
157	Fishery Support Vessel	Support ship	11
162	Kelp Dredger	Support ship	11
163	Kelp Dredger	Support ship	11
166	Offshore Supply	Support ship	11
167	Platform Supply Ship	Support ship	11
168	Crew/Supply Vessel	Support ship	11
169	Pipe Carrier	Support ship	11
170	Platform Supply Ship	Support ship	11
171	Offshore Tug/Supply Ship	Support ship	11
172	Anchor Handling Tug Supply	Support ship	11
173	Offshore Tug/Supply Ship	Support ship	11
174	Other Offshore	Support ship	11
175	Offshore Support Vessel	Support ship	11
176	Offshore Support Vessel	Support ship	11
177	Diving Support Vessel	Support ship	11
178	Drilling Ship	Support ship	11
179	Drilling Ship	Support ship	11
180	Pipe Layer	Support ship	11
181	Pipe Layer Crane Vessel	Support ship	11
182	Pipe Layer	Support ship	11
183	Production Testing Vessel	Support ship	11
184	Production Testing Vessel	Support ship	11
185	FPSO (Floating, Production, Storage, Offloading)	Support ship	11

ID	LR shiptype	BaSSy shiptype	Code
186	FPSO, Oil	Support ship	11
187	FPSO, Gas	Support ship	11
188	Well Stimulation Vessel	Support ship	11
189	Well Stimulation Vessel	Support ship	11
190	Standby Safety Vessel	Support ship	11
191	Standby Safety Vessel	Support ship	11
192	FSO (Floating, Storage, Offloading)	Support ship	11
193	FSO, Oil	Support ship	11
194	Trenching Support Vessel	Support ship	11
195	Trenching Support Vessel	Support ship	11
196	Pipe Burying Vessel	Support ship	11
197	Pipe Burying Vessel	Support ship	11
198	MISCELLANEOUS	Support ship	11
202	Towing/Pushing	Support ship	11
203	Tug	Support ship	11
204	Tug	Support ship	11
205	Tug	Support ship	11
206	Pusher Tug	Support ship	11
207	Dredging	Support ship	11
208	Dredger	Support ship	11
209	Bucket Dredger	Support ship	11
210	Cutter Suction Dredger	Support ship	11
211	Grab Dredger	Support ship	11
212	Suction Dredger	Support ship	11
213	Dredger (unspecified)	Support ship	11
214	Hopper Dredger	Support ship	11
215	Hopper/Bucket Dredger	Support ship	11
216	Hopper/Grab Dredger	Support ship	11
217	Hopper/Suction Dredger	Support ship	11
218	Hopper/Dredger (unspecified)	Support ship	11
219	Other Activities	Support ship	11
220	Motor Hopper	Support ship	11
221	Hopper, Motor	Support ship	11
222	Stone Carrier	Support ship	11
223	Crane Ship	Support ship	11
224	Crane Ship	Support ship	11
225	Pile Driving Vessel	Support ship	11
226	Icebreaker	Support ship	11
227	Icebreaker	Support ship	11
228	Icebreaker/Research	Support ship	11
229	Cable Layer	Support ship	11
230	Cable Layer	Support ship	11
231	Waste Disposal Vessel	Support ship	11
232	Incinerator	Support ship	11
233	Waste Disposal Vessel	Support ship	11
234	Effluent Carrier	Support ship	11
235	Fire Fighting Vessel	Support ship	11
236	Fire Fighting Vessel	Support ship	11
237	Pollution Control Vessel	Support ship	11
238	Pollution Control Vessel	Support ship	11
239	Patrol Vessel	Support ship	11
240	Patrol Vessel	Support ship	11
241	Crew Boat	Support ship	11
242	Crew Boat	Support ship	11
243	Training Ship	Support ship	11
244	Training Ship	Support ship	11
245	Utility Vessel	Support ship	11
246	Utility Vessel	Support ship	11
247	Search & Rescue Vessel	Support ship	11
248	Search & Rescue Vessel	Support ship	11
249	Pilot Vessel	Support ship	11
250	Pilot Vessel	Support ship	11
251	Salvage Ship	Support ship	11
252	Salvage Ship	Support ship	11
253	Buoy/Lighthouse Vessel	Support ship	11
254	Buoy Tender	Support ship	11
255	Buoy & Lighthouse Tender	Support ship	11
256	Lighthouse Tender	Support ship	11
257	Supply Tender	Support ship	11
258	Supply Tender	Support ship	11
259	Mooring Vessel	Support ship	11
260	Mooring Vessel	Support ship	11
261	Work/Repair Vessel	Support ship	11
262	Work/Repair Vessel	Support ship	11
265	Tank Cleaning Vessel	Support ship	11
266	Tank Cleaning Vessel	Support ship	11
267	Trans Shipment Vessel	Support ship	11
268	Trans Shipment Vessel	Support ship	11
269	Log Tipping Ship	Support ship	11
270	Log Tipping Ship	Support ship	11
271	Other Activities cont./	Support ship	11
272	Leisure Vessels	Support ship	11
273	Exhibition Vessel	Support ship	11
274	Theatre Vessel	Support ship	11
275	Mission Ship	Support ship	11
276	Dry Storage	Support ship	11
277	Bulk Dry Storage Ship	Support ship	11
278	Bulk Cement Storage Ship	Support ship	11
279	Mining Vessel	Support ship	11
280	Mining Vessel	Support ship	11
281	Wind Turbine Vessel	Support ship	11
282	Wind Turbine Installation Vessel	Support ship	11
283	Wind Turbine Installation Vessel (semi	Support ship	11
320	Inland Waterways Towing/Pushing	Support ship	11
321	Towing/Pushing, Inland Waterways	Support ship	11
322	Inland Waterways Dredging	Support ship	11
323	Dredging, Inland Waterways	Support ship	11
324	Inland Waterways Other Activities	Support ship	11
325	Other Activities, Inland Waterways	Support ship	11
139	Fish Catching	Fishing ship	12

ID	LR shiptype	BaSSy shiptype	Code
140	Trawler	Fishing ship	12
141	Factory Stern Trawler	Fishing ship	12
142	Stern Trawler	Fishing ship	12
143	Trawler	Fishing ship	12
144	Fishing Vessel	Fishing ship	12
145	Fishing Vessel	Fishing ship	12
146	Other Fishing	Fishing ship	12
147	Fish Factory Ship	Fishing ship	12
148	Fish Factory Ship	Fishing ship	12
158	Seal Catcher	Fishing ship	12
159	Seal Catcher	Fishing ship	12
160	Whale Catcher	Fishing ship	12
161	Whale Catcher	Fishing ship	12
316	Inland Waterways Fishing	Fishing ship	12
317	Fishing, Inland Waterways	Fishing ship	12
132	Heavy Load Carrier, semi	Other ship	13
133	Yacht Carrier, semi submersible	Other ship	13
156	Fishery Research Vessel	Other ship	13
199	Research	Other ship	13
200	Research Vessel	Other ship	13
201	Research Survey Vessel	Other ship	13
286	Vessel (function unknown)	Other ship	13
287	Vessel (function unknown)	Other ship	13
288	Sailing Vessel	Other ship	13
289	Sailing Vessel	Other ship	13
315	Inland Waterways Other Non	Other ship	13
318	Inland Waterways Research	Other ship	13
319	Research, Inland Waterways	Other ship	13
326	Non Merchant Ships	Other ship	13
328	Houseboat	Other ship	13
331	Sail Training Ship	Other ship	13
332	Sail Training Ship	Other ship	13
333	Naval/Naval Auxiliary	Other ship	13
334	Crane Vessel, Naval Auxiliary	Other ship	13
335	Crew Boat, Naval Auxiliary	Other ship	13
336	Replenishment Dry Cargo	Other ship	13
337	Hospital Vessel, Naval Auxiliary	Other ship	13
338	Mooring Vessel, Naval Auxiliary	Other ship	13
339	Repair Vessel, Naval Auxiliary	Other ship	13
340	Training Ship, Naval Auxiliary	Other ship	13
341	Research Vessel, Naval	Other ship	13
342	Replenishment Tanker	Other ship	13
343	Unknown Function, Naval/Naval	Other ship	13
344	Diving Vessel, Naval Auxiliary	Other ship	13
345	Tug, Naval Auxiliary	Other ship	13
346	Salvage Vessel, Naval Auxiliary	Other ship	13
347	Naval Small Craft	Other ship	13
348	Boom defence Vessel	Other ship	13
349	Degaussing Vessel	Other ship	13
350	Minehunter	Other ship	13
351	Minelayer	Other ship	13
352	Minesweeper	Other ship	13
353	Netlayer	Other ship	13
354	Torpedo Recovery Vessel	Other ship	13
355	Troopship	Other ship	13
356	Munitions Carrier	Other ship	13
357	Submarine Salvage Vessel	Other ship	13
358	Aircraft Carrier	Other ship	13
359	Command Vessel	Other ship	13
360	Corvette	Other ship	13
361	Destroyer	Other ship	13
362	Escort	Other ship	13
363	Frigate	Other ship	13
364	Cruiser	Other ship	13
365	Helicopter Carrier	Other ship	13
366	Attack Vessel, Naval	Other ship	13
367	Patrol Vessel, Naval	Other ship	13
368	Torpedo Trials Vessel	Other ship	13
369	Weapons Trials Vessel	Other ship	13
370	Submarine Chaser	Other ship	13
371	Torpedo Boat	Other ship	13
372	Water Tanker, Naval Auxiliary	Other ship	13
373	Logistics Vessel (Naval RoRo	Other ship	13
374	Infantry Landing Craft	Other ship	13
375	Landing Ship (Dock Type)	Other ship	13
376	Tank Landing Craft	Other ship	13
377	Submarine	Other ship	13
378	Other Non Merchant Ships	Other ship	13
379	Training Ship	Other ship	13
380	Accommodation Vessel,	Other ship	13
381	Lightship	Other ship	13
382	Museum, Stationary	Other ship	13
383	Restaurant Vessel, Stationary	Other ship	13
384	Radio Station Vessel	Other ship	13
385	NON PROPELLED	Other ship	13
386	Non Propelled	Other ship	13
387	Non Propelled Barge	Other ship	13
388	Bulk Aggregates Barge, non	Other ship	13
389	Covered Bulk Cargo Barge, non	Other ship	13
390	Bulk Cement Barge, non	Other ship	13
391	Fish Storage Barge, non	Other ship	13
392	General Cargo Barge, non	Other ship	13
393	Bitumen Tank Barge, non	Other ship	13
394	Trans Shipment Barge, non	Other ship	13
395	Water Tank Barge, non	Other ship	13
396	Hopper Barge, non propelled	Other ship	13
397	Cement Storage Barge, non	Other ship	13
398	Chemical Tank Barge, non	Other ship	13
399	LPG Tank Barge, non propelled	Other ship	13
400	Products Tank Barge, non	Other ship	13



ID	LR shiptype	BaSSy shiptype	Code
401	Chemical/Products Tank Barge, non	Other ship	13
402	Crude Oil Tank Barge, non propelled	Other ship	13
403	Pontoon	Other ship	13
404	Deck Cargo Pontoon, semi submersible	Other ship	13
405	Jacket Launching Pontoon, semi	Other ship	13
406	Bucket Dredger Pontoon	Other ship	13
407	Deck Cargo Pontoon, non propelled	Other ship	13
408	Grab Dredger Pontoon	Other ship	13
409	Suction Dredger Pontoon	Other ship	13
410	Dredging Pontoon, unknown dredging	Other ship	13
411	Water Jet Dredging Pontoon	Other ship	13
412	Crane Pontoon	Other ship	13
413	Electricity Generating Pontoon, non	Other ship	13
414	Grain Elevating Pontoon, non propelled	Other ship	13
415	Sheerlegs Pontoon	Other ship	13
416	Desalination Pontoon, non propelled	Other ship	13
417	Shopping COMPLEX	Other ship	13
418	Steam Supply Pontoon, non propelled	Other ship	13
419	Car Park	Other ship	13
420	Work/Maintenance Pontoon, non	Other ship	13
421	Pontoon (function unknown)	Other ship	13
422	NON SHIP STRUCTURES	Other ship	13
423	Non Ship Structures	Other ship	13
424	Air Cushion Vehicle (Hovercraft)	Other ship	13
425	Air Cushion Vehicle Passenger/RoRo	Other ship	13
426	Air Cushion Vehicle Passenger	Other ship	13
427	Air Cushion Vehicle, work vessel	Other ship	13
428	Wing In Ground EFFECT Vessel	Other ship	13
429	Air Cushion Vehicle Patrol Vessel	Other ship	13
430	Floating Dock	Other ship	13
431	Dock Gate	Other ship	13
432	Floating Dock	Other ship	13
433	Mechanical Lift Dock	Other ship	13
434	Platform	Other ship	13
435	Accommodation Platform, semi	Other ship	13
436	Drilling Rig, semi Submersible	Other ship	13
437	Diving Support Platform, semi	Other ship	13
438	Pipe layer Platform, semi submersible	Other ship	13
439	Maintenance Platform, semi Submersible	Other ship	13
440	Accommodation Platform, jack up	Other ship	13
441	Crane Platform, jack up	Other ship	13
442	Drilling Rig, Jackup	Other ship	13
443	Maintenance Platform, jack up	Other ship	13
444	Supply Platform, jack up (Lift Boat)	Other ship	13
445	Pumping Platform	Other ship	13
446	Buoy	Other ship	13
447	Mooring Buoy	Other ship	13
448	Linkspan/Jetty	Other ship	13
449	Linkspan/Jetty	Other ship	13
451	Unknown	Other ship	13
327	Yacht	Pleasure boat	14
329	Yacht	Pleasure boat	14
330	Yacht (Sailing)	Pleasure boat	14
452	Pleasure boat	Pleasure boat	14