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Memo Project on sub-regional risk of spill of oil and hazardous substances in the Baltic Sea (BRISK)

Title Collision frequency model

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To Appendix of Part 4 of the Model Report

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From ALBL

1 Introduction

This memo describes the establishment of the collision frequency model and is part of the grounding risk analysis described in Part 4 of the Model Report.

2 Route collisions

Basic concepts

When two ships collide while sailing on the same route, this is referred to as route collision. There are two basic cases:

- Head-on collisions between two ships heading in opposed directions
- Overtaking collisions between two ships heading in the same direction

These two cases are illustrated in Figure 1.

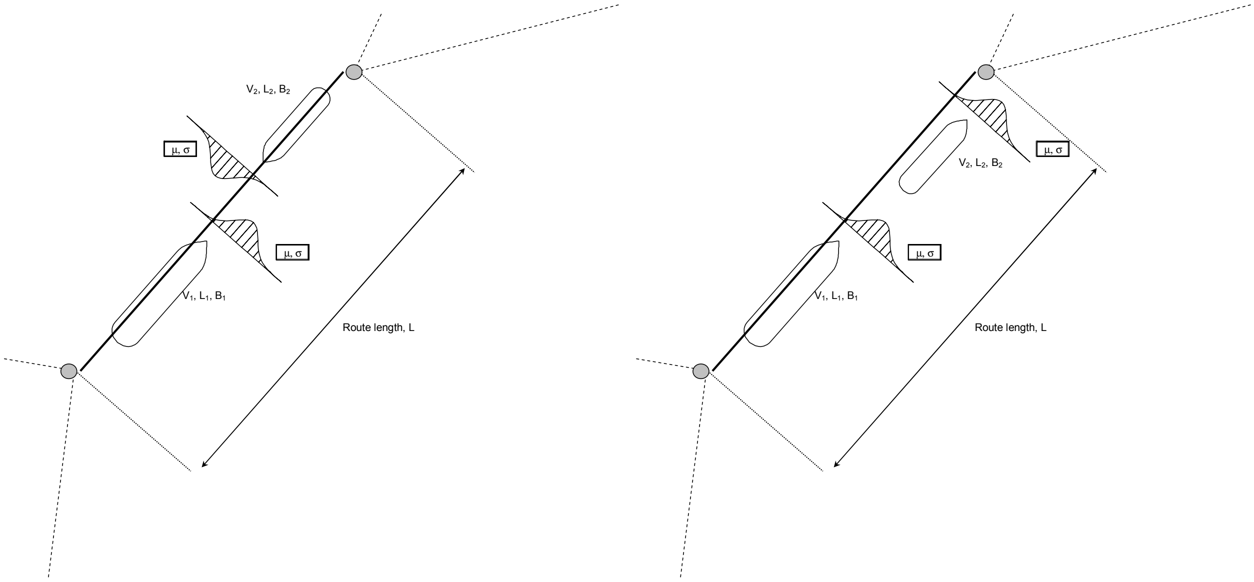

Figure 1 Head-on and overtaking collisions

Route collision frequencies depend on

- the length of the route segment
- the traffic intensity in each of the two directions
- width and speed of the ships
- the deviation of the ships from the route axis
- causation probability P_C, i.e. the probability that none of the ships bound for collision undertakes successful evasive action.

Data input

The ship and traffic data described in Part 1 of the Model Report provide this kind of information for each route leg.

Calculation

In the course of calculation, every ship (ship$_1$) is combined with every possible collisions partner (ship$_2$). Then, their collision probability is calculated.

Both ship$_1$ and ship$_2$ have an array of properties such as ship type, speed, size, breadth which are all taken into account. Some of this properties are directly relevant for the collision probability (breadth, speed), whereas others are relevant for the consequences of the collision (ship type and size).

Two ships sailing along the same route collide with a yearly frequency of

$$P_X = P_t P_g P_c k_{RR}$$

where P_t … yearly frequency of meeting within one route segment (a matter of time and route length)
P_G … geometrical collision probability (a matter of width)
P_C … causation probability
k_{RR} … risk reduction factor

These partial probabilities are obtained as

Meeting frequency

$$P_t = L N_1 N_2 \left| \frac{V_1 - V_2}{V_1 V_2} \right|$$

where L … length of route segment
N_1, N_2 … yearly number of passings (ship$_1$, ship$_2$)
V_1, V_2 … vessel speed (ship$_1$, ship$_2$)

Geometrical collision probability

$$P_g = \Phi\left(\frac{\left|\mu_1 - \mu_2 + \overline{B}\right|}{\overline{\sigma}} \right) - \Phi\left(\frac{\left|\mu_1 - \mu_2 - \overline{B}\right|}{\overline{\sigma}} \right)$$

with

$$\overline{B} = \frac{B_1 - B_2}{2} \qquad \text{and} \qquad \overline{\sigma} = \sqrt{\sigma_1^2 + \sigma_2^2}$$

where μ_1, μ_2 … mean value of the transversal position of $ship_1$ and $ship_2$, respectively, relative to the route axis

σ_1, σ_2 … standard deviation of the transversal position of $ship_1$ and $ship_2$, respectively, relative to the route axis

B_1, B_2 … vessel breadth ($ship_1$, $ship_2$)

Causation probability

The probability that two ships sailing on collision course do *not* undertake any evasive measures is called causation probability P_C. This quantity is based on statistics and modelling by Fujii /Fujii/. In the context of the Storebælt link investigation Fujii's result was adapted to the situation in Danish waters, resulting in a value of $P_C = 3.2 \times 10^{-4}$. A value of $P_c = 3.0 \times 10^{-4}$ was chosen in the analysis of oil and chemical spill risk in Danish waters, because it was found consistent with the observed accident rate during the past 10-15 years /Oil spill DK, 2007/.

Applied to the BRISK area, this would correspond to approximately three collisions between ships of at least 300 gross tonnage per year. As a matter of fact, the historical number of accidents is about twice as high, e.g. six collisions per year (2004-2008 average). This would roughly correspond to a value of $P_c = 6 \times 10^{-4}$.

However, it should be considered that the historical data also include low-energy events which are not considered by the model. Setting the causation probability up in order to match the historical data would therefore result in a problematic overestimation of collisions under full vessel speed and thus of the risk of actual spills.

Moreover, Figure 2 appears to indicate that multiple risk-reduction efforts during recent years are having an effect and that the overall collision frequency in the BRISK area is decreasing. The low numbers for 2004 are mostly due to the fact that ship sizes were not indicated in several cases in that year, i.e. many ships of 300 GT and upwards are not identifiable as such. Many risk-reducing measures such as some of the VTS centres only became fully effective after 2006, which might explain the lower accident numbers during recent years.

Bearing all these considerations and the values used in earlier analyses in mind, it appears neither realistic to use $P_c = 3.0 \times 10^{-4}$ as in earlier cases, nor to set the value as high as $P_c = 6.0 \times 10^{-4}$. As an alternative to those values, it appears reasonable to adopt the following causation probability for the BRISK area:

$P_c = 4.0 \times 10^{-4}$

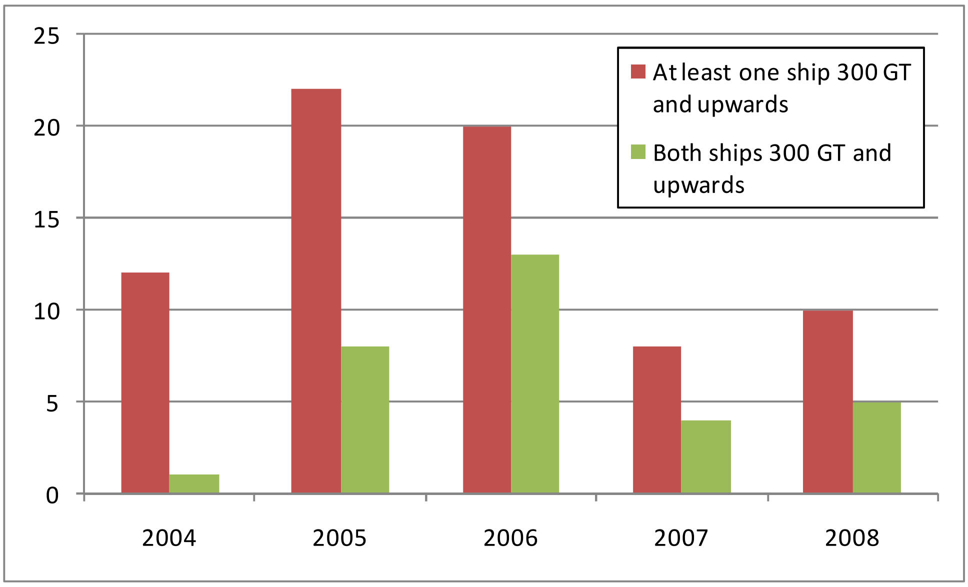

Figure 2 *Number of collision in the BRISK area per year, 2004-2008*

In the specific case of the Drogden channel, a local causation factor of $P_C = 1.3 \times 10^{-4}$ is chosen based on an earlier location-specific analysis /Drogden, 2001/. Using a value of 4.0×10^{-4} would lead to a much higher accident frequency than actually observed. The fact that the Drogden channel is the single most accident-prone location in the entire BRISK area justifies this separate modelling decision.

Risk reduction factor

Different factors can have a reducing factor upon collision risk. These factors are described in Part 4 of the Model Report.

3 Node collisions

Any ship-ship collision that does not involve two ships sailing on the same route is classified as node collision.

Basic concepts

The node collision frequency is calculated based on

- the crossing pattern
- the traffic intensity in each of the two directions
- width, length and speed of the ships
- the crossing angle
- causation probability P_C, i.e. the probability that none of the ships bound for collision undertakes successful evasive action.

- the probability that the traces of both ships intersect

Calculation

Based on these considerations, yearly collision frequency can be written as

$$P_X = P_i P_g P_c k_{RR}$$

where P_i … probability that the traces of the two ship_1 and ship_2 intersect
P_g … geometrical collision frequency (per year)
P_c … causation probability
k_{RR} … risk reduction factor

Intersecting probability

/Oil spill DK, 2007/ includes long and detailed considerations on how to estimate the correct intersection probability. However, the study concluded that there was too little theoretical or practical evidence for deriving a correct value and modelled the probability as $P_i = 1$.

Essentially, there are two basic kinds of crossings: X-crossings (full intersection) and Y-crossings (merging/splitting traffic). All other crossing can be seen as a combination of several X- and Y-crossings.

In the case of X-crossings, the traces of two ships sailing on different routes will necessarily intersect. In this case, $P_i = 1$ appears to be the correct choice, also from a theoretical point of view.

In the case of Y-crossings, the situation is less obvious. /Oil spill DK, 2007/ includes long and detailed consideration on how to estimate the correct intersection probability. However, the study concluded that there was too little theoretical or practical evidence for deriving a correct value and modelled the probability as $P_i = 1$ for all cases.

Geometrical collision probability

The possibility of a collision between two ships following intersecting routes depends upon the angle θ between the routes, the geometry of the ships and their speed. This possibility can be expressed by means of a critical time interval Δt or a critical length $L_K = \Delta t\ V_2$ for ship_2. The meaning of these quantities is illustrated in Figure 3:

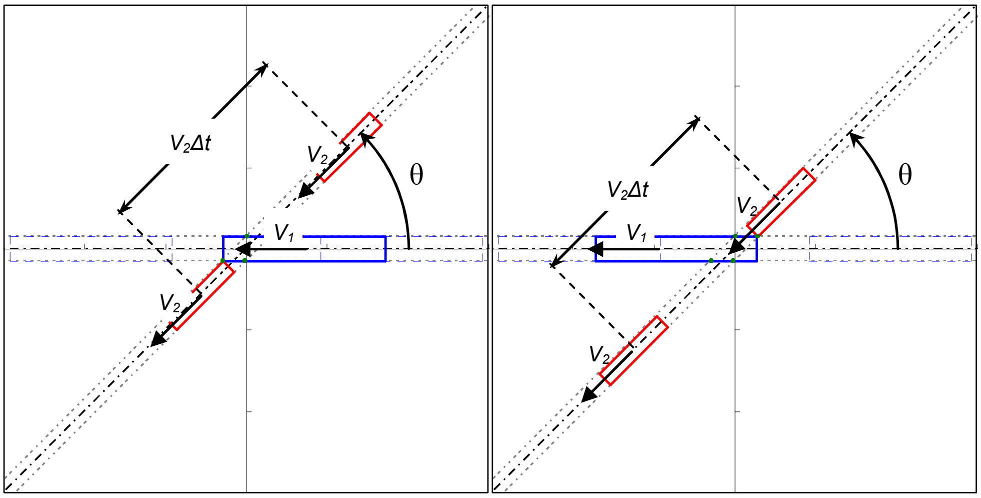

Figure 3 *Geometrical determination of the critical time interval/route length for a node collision*

The critical time interval is determined as

$$\Delta t = \frac{1}{\left|V_1 V_2\right|}\left[B_2\left|\frac{V_2}{\sin\theta} - \frac{V_1}{\tan\theta}\right| + B_1\left|\frac{V_1}{\sin\theta} - \frac{V_2}{\tan\theta}\right| + L_1\left|V_2\right| + L_2\left|V_1\right|\right]$$

The passage of ships on one of the two routes is assumed to be a Poisson process. As a consequence, the geometrical collision frequency follows as

$$\begin{aligned} P_g &= N_1\left(1 - e^{-N_2\Delta t}\right) \\ &\approx N_1 N_2 \Delta t \end{aligned}$$

Causation probability

This quantity is chosen as

$P_c = 4.0 \times 10^{-4}$

for the same reasons as for route collisions above.

Risk reduction factor

Different factors can have a reducing factor upon collision risk. These factors are described in Part 4 of the Model Report.

4 References

/Drogden, 2001/ Copenhagen Port: *Drogden feasibility studie 2001, Aktivitet 3.9, Søuheld (in Danish)*, HLD Joint Venture, December 2001

/Oil spill DK, 2007/ *Risikoanalyse: Olie- og kemikalieforurening i danske farvande (Risk analysis: Oil and chemicals pollution in Danish waters)*, prepared for Danish Ministry of Defence by COWI, COWI report 63743-1-01, October 2007