Co-funded by the European Union

BRISK II

Accident and spill model

Deliverable 2.5

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This document is developed within the BRISK II project to update the model for accidents and spills in the Baltic Sea and submitted by the Core Project team on 28.02.2026.

BRISK II, Long-term risk analysis for oil and hazardous and noxious substances (HNS) pollution from shipping accidents to the marine environment in the Baltic Sea, is a project co-funded by the EU. Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or DG ECHO. Neither the European Union nor the granting authority can be held responsible for them.

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BRISK II

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APPENDICES

1 Introduction

1.1 Background

This data report is part of the long-term risk analysis for oil and hazardous and noxious substances (HNS) pollution from shipping accidents to the marine environment in the Baltic Sea, in short BRISK II. The BRISK II project comprises the following deliverables on the analyses:

1 Deliverables under work package 1 include project management related reports (e.g. progress reports).

2 Work package 2: Basic analysis
- 2.1 Method note
- 2.2 Data collection note
- 2.3 Traffic analysis
- 2.4 Cargo analysis
- **2.5 Accident and spill model (this report)**
- 2.6 Probability of oil and HNS release

3 Work package 3: Future damage analysis
- 3.1 Traffic scenarios
- 3.2 Selection of risk reduction scenarios
- 3.3 Impact mapping of spilt oil and HNS
- 3.4 Mapping of environmental vulnerability
- 3.5 Mapping of environmental damage due to oil
- 3.6 Mapping of environmental damage due to HNS

1.2 Scope

This report deals with the accident and spill model regarding oil and hazardous or noxious substances. The relevant spill scenarios have been identified and discussed in the Method note (BRISK II, Method note, 2025). They comprise the following events occurring in the open sea with vessels of a gross tonnage of 300 and above:

- Ship accidents (ship-ship collisions, groundings, fire, collisions with fixed objects, foundering etc.)
- Operational spills from ships
- STS operations and bunkering at sea
- Offshore oil and gas activities (as far as releases from the involved vessels are concerned)

The report describes the model that is used for calculating the probability of these accident types, the ensuing probability of spills and the size distribution of the spills. The report does not present the results of the probability calculation – they are shown in a separate deliverable, *D2.6 Probability of oil and HNS release* (BRISK II, Prob. of release, 2026), see also Figure 1-1.

Also, it is important to highlight that BRISK II is update of BRISK I. This means that the newest data on traffic, cargo, fixed objects, prevention and response measures are taken into account whereas the basic methodology is maintained unchanged in most parts compared to BRISK I. Changes to the methodology are only made when mandated by a change in the real world, such as the appearance of the shadow fleet. Another such change is the emergence of offshore wind farms, which were an almost negligible phenomenon during BRISK I.

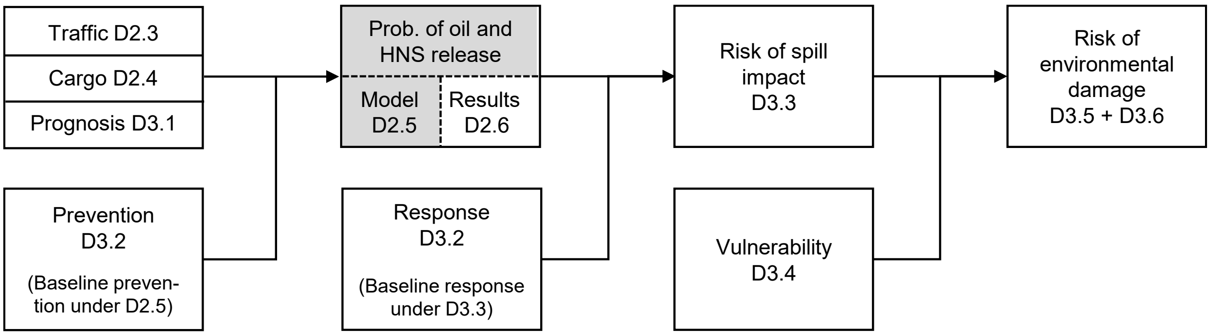


Figure 1-1 *Causal chain of the BRISK II model and corresponding deliverables numbers (The present report is highlighted with grey background)*

The accident and spill model report is divided into the following chapters:

Chapter 2: Spill size classes
Chapter 3: Ship accidents
Chapter 4: Operational spills from ships
Chapter 5: Offshore oil transfer
Chapter 6: Spill from offshore installations

2 Spill size classes

The model indicates a separate spill frequency for each spill size class. The following spill size classes are used in the results:

Table 2-1 Spill size classes used in the BRISK results (all values in tonnes (t))

Spill size class	Lower limit [t]	Upper limit [t]	Representative size [t]
0	0	0	0
1	0	1	0.3
2	1	15	4
3	15	300	67
4	300	5,000	1,200
5	5,000	15,000	8,700
6	15,000	50,000	27,000
7	50,000	150,000	87,000

3 Ship accidents

3.1 Historical accidents in the Baltic Sea

Accident types

HELCOM has been publishing shipping accident data in the Baltic Sea since of 1989. Not all accidents are of equal relevance in connection with BRISK II. Table 3-1 displays the HELCOM accident types and groups them according to their pollution potential. Accident types that are either unlikely to ensue in pollution or where it is unlikely that pollution events are of a significant size (more than a few litres) are not taken into consideration.

Note that the BRISK II project area also includes the Swedish North Sea and is thus slightly bigger than the HELCOM area, which is limited to the Baltic Sea. The collected accident data only cover the Baltic Sea[1].

Table 3-1 HELCOM accident types

HELCOM accident types of relevant pollution risk	HELCOM accident types of minor or negligible pollution risk
Collision with vessel Collision with object Grounding/Stranding Fire/Explosion Capsizing/listing Pollution[2] Damage to ship or equipment	Damage to ship or equipment Technical failure Other

Data quality

Data quality has not been consistent during the entire data collection period (2015-2024). During 2015–2017, the number of reported accidents remained relatively stable at a lower level. From 2018 onwards, a significant increase is observed, with accident numbers peaking around 2021, after which they show a slight decline but remain at a comparatively high and stable level (Figure 3-1). This development is partly related to changes in the HELCOM accident reporting system. However, when filtering for the major accident types that are relevant for the BRISK II project (see Figure 3-2), the observed discrepancy disappears. Major accidents tend to be reported more consistently than minor incidents. The reason is that it is

[1] This is an acceptable limitation, as the main purpose of the accident data is calibration of accident rates. Calibration is based on the Baltic Sea are alone, whereas the calibrated model can then be applied to the entire BRISK II project area.

[2] The accident type Pollution is excluded from the accident statistics in this chapter and is analysed separately in Chapter 4.

often unclear when a minor incident is worth recording This phenomenon is common also in other domains, e.g. road traffic accidents.

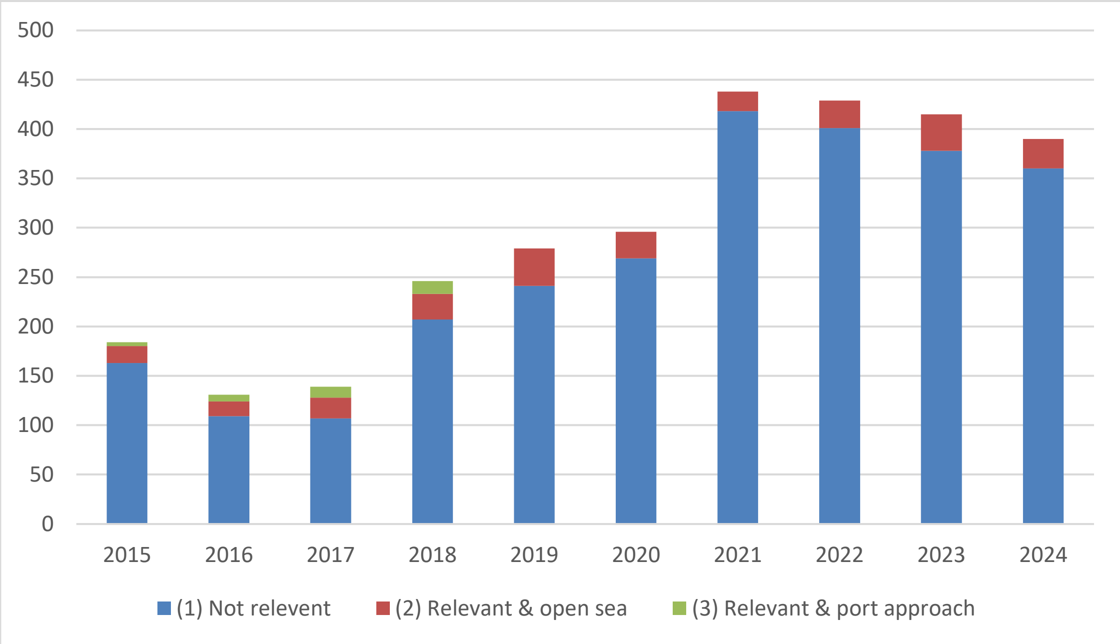


Figure 3-1 *Number of accidents in the HELCOM database, 2015-2024: (1) not relevant accident types and port accidents; (2) relevant accidents in open sea areas; and (3) relevant accidents in port-approach areas*

To ensure consistency with the BRISK II modelling scope, the dataset is cleaned by removing accident types that are not relevant for pollution risk assessment (see Table 3-1), as well as accidents occurring in areas not covered by the BRISK II scope (see BRISK II, Method note, 2025). In addition, port accidents are excluded. For accidents classified as *port approach*, only those located on continuous traffic corridors where vessels pass through as part of a linear movement were considered relevant, while accidents occurring in manoeuvring, stopping, or harbour areas were removed. Figure 3-2 shows the resulting accident statistics after applying these filters, which are substantially lower than those in Figure 3-1 due to the more restrictive scope.

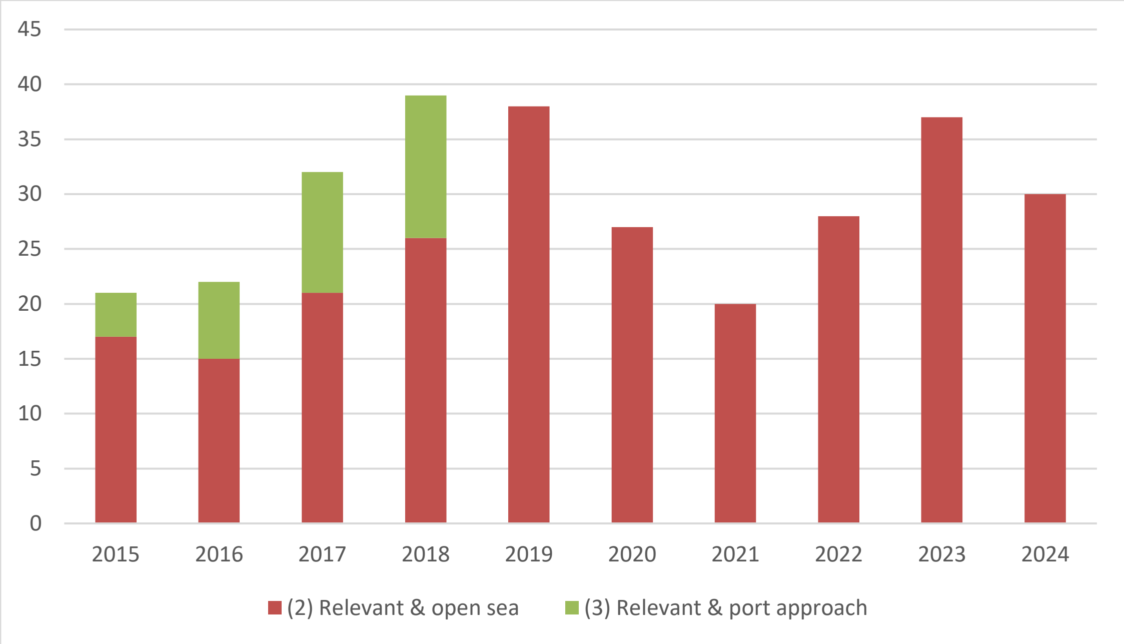


Figure 3-2 *Number of accidents, 2015-2024: (2) relevant accidents in open sea areas; and (3) relevant accidents in port-approach areas*

As shown in Figure 3-2, the annual number of accidents increases from approximately 20 on average in 2015–2016 to a peak around 2018–2019, followed by a decline to another minimum around 2021. This is then followed by a renewed increase in 2022–2023 and a slight decrease in 2024. Although the absolute numbers differ between the two filtering approaches, both figures exhibit the same overall temporal pattern. These variations may be influenced by changes in traffic intensity, operating conditions, and reporting practices.

Number of accidents

Table 3-2 and Table 3-3 display the observed number of accidents per accident type and country during 2015-2024.

Table 3-2 *Total number of shipping accidents in the Baltic Sea 2015-2024 (HELCOM database plus national corrections, only relevant accident types, without port accidents but with relevant port approach accidents included)*

Accident type	DE	DK	EE	FI	LT	LV	PL	RU	SE	Total
Collision with object	9	11		2	1	1	10		12	46
Collision with vessel	6	21	1	8	1		5	2	23	67
Damage to ship or equipment									3	3
Fire/Explosion	15	17	1	2		2	4	1	15	57
Grounding/Stranding	9	62	4	8			2		32	117
Capsizing/listing									1	1
Total	*39*	*111*	*6*	*20*	*2*	*3*	*21*	*3*	*86*	*291*

Table 3-3 Total number of shipping accidents in the Baltic Sea 2015-2024 (HELCOM database plus national corrections, only relevant accident types, without port accidents and port approach accidents)

Accident type	DE	DK	EE	FI	LT	LV	PL	RU	SE	Total
Collision with object	9	10		2	1	1	2		12	37
Collision with vessel	6	19	1	7	1		2	2	23	61
Damage to ship or equipment									3	3
Fire/Explosion	15	17	1	2		1	4	1	15	56
Grounding/Stranding	9	51	3	4			2		31	100
Capsizing/listing									1	1
Total	*39*	*97*	*5*	*15*	*2*	*2*	*10*	*3*	*85*	*258*

Accident locations are illustrated in Figure 3-3 and Figure 3-4. Accidents are concentrated in areas where a large number of ships navigate under complicated narrow and/or complex conditions. This is typically the case in narrow straits (e.g. Great Belt and The Sound), close to ports and at major sea route intersections (e.g. Gulf of Finland between Helsinki and Tallinn). Additional clusters are observed in regions with complex coastlines, shallow waters, and numerous islands and reefs, such as the Sea of Åland.

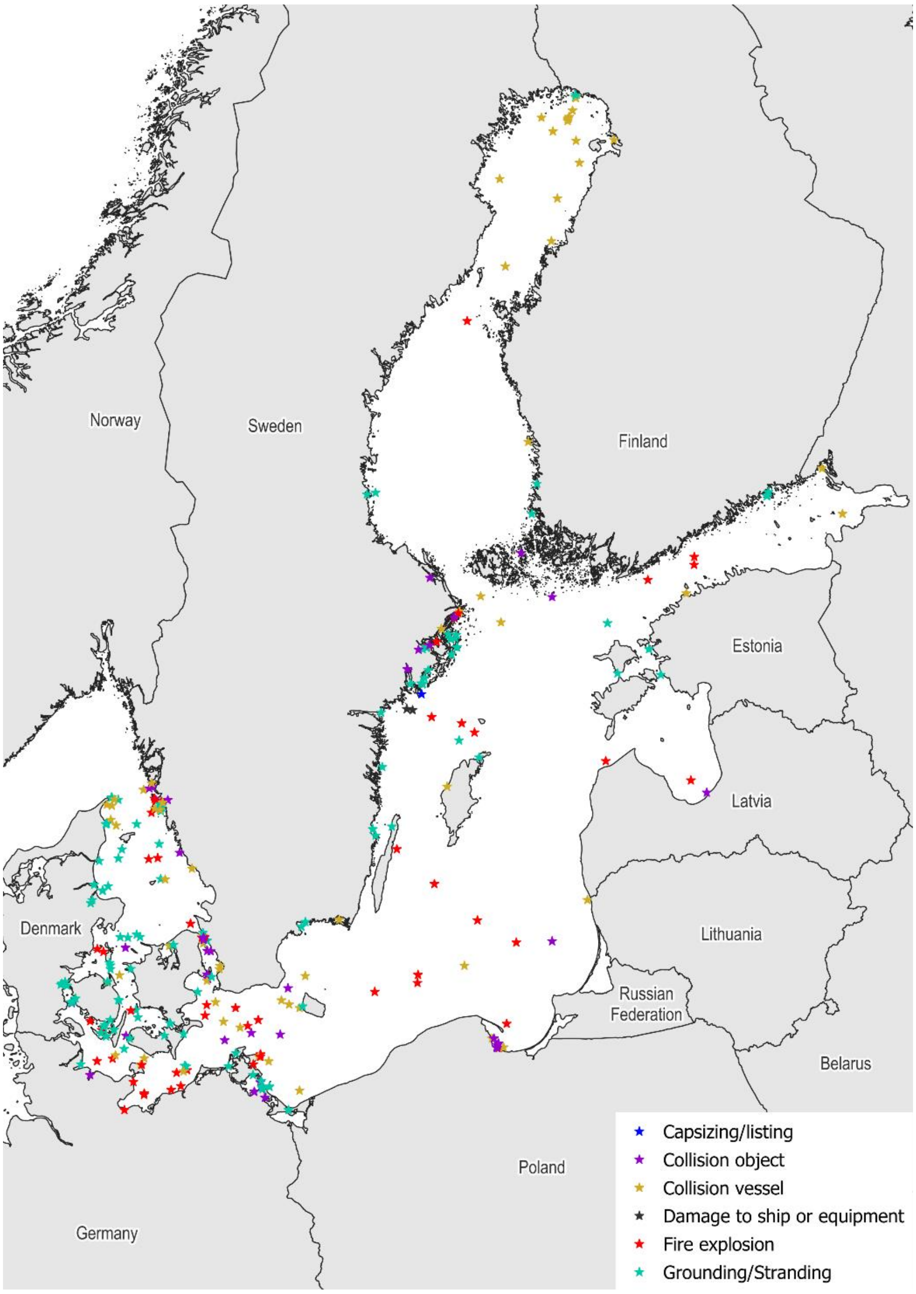


Figure 3-3 *Accidents in the Baltic Sea, 2015-2024: HELCOM database plus national corrections, only relevant accident types, without accidents, relevant port approach accidents included*

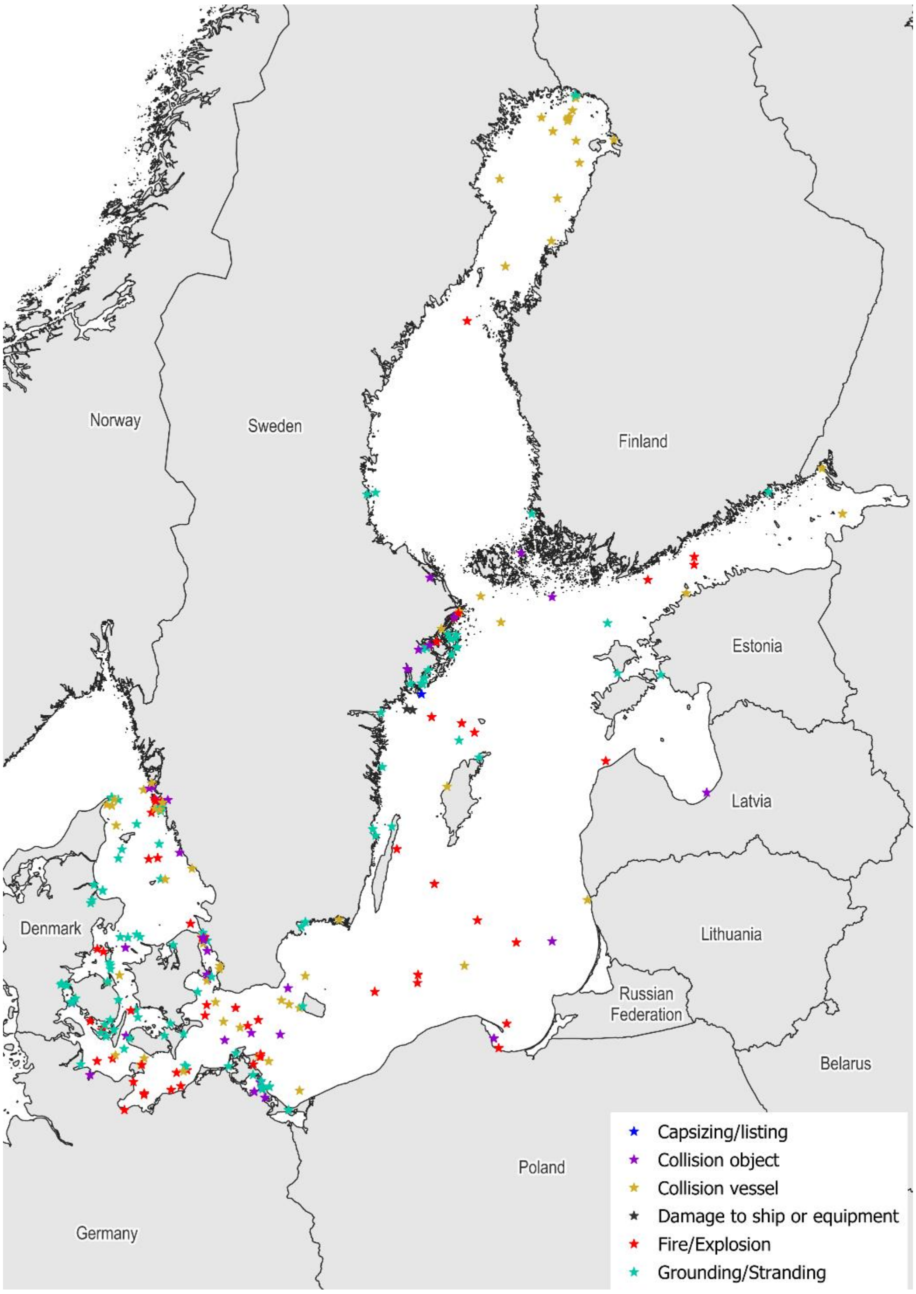


Figure 3-4 *Accidents in the Baltic Sea, 2015-2024: HELCOM database plus national corrections, only relevant accident types, all port and port approach accidents excluded*

Accidents involving spillage

Of all the relevant accidents occurred during 2015-2024, five accidents were associated with a reported release of a substance, three of these led to pollution with a relevant substance (oil), i.e. one of the substances identified in the Method note (BRISK II, Method note, 2025). No cases involving other hazardous or noxious substances are registered (Table 3-4).

Of the two recorded oil spill accidents, one involved a spill of 25 m^3, while the other did not report the released amount.

As shown in Table 3-4, the number of accidents during the 10-year period 2015-2024 is lower than during the 5-year period 2004-2008 that was used for BRISK I (BRISK I, Spill, 2012). Also, the number of spills during 2015-2024 (four events, one larger than 1 m^3) is smaller than during 2004-2008 (14 events, three larger than 1 m^3). When considering the length of the statistical periods (10 vs. 5 years), this means that the annual number of accidents has been decreased by a factor 2.5, whereas the annual number of spills has decreased by a factor of 6.

The largest single release during 2004-2008 was 150 m^3 of oil. There occurred a number of relevant events in the years before 2004, most notably the collision between *Fu Shan Hai* and *Gdynia* in the Bornholmsgat in 2003 (Denmark/Sweden, 500 tonnes of oil released) and the collision between *Baltic Carrier* and *Tern* in 2001 in the Kadetrenden (Germany/Denmark, 2700 tonnes of oil released). The latter event caused the largest coast pollution of the Danish coastline in the history of the country.

Illegal discharges, i.e. deliberate or inadvertent events, are analysed separately in Section 4.

Table 3-4 Pollution events due to accidents in the Baltic Sea 2015-2024 (basis for BRISK II) and 2004-2008 (basis for BRISK I)

Pollution	Number of accidents 2015-2024	Number of accidents 2004-2008
Yes, of which:	5	14
Oil	*3*	*11*
Other relevant substance	*0*	*0*
Non-relevant substance	*2*	*3*
No	270	336
Not indicated	16	13
Total	291	363

Spill from accidents with small ships

In the case of ships below 300 GT, which are not required to carry AIS transponders and are not covered by the accident model, oil spill databases are a useful means of assessing the relative importance of this contribution. Earlier experience (Oil spill DK, 2007) shows that oil spills due to ship accidents exclusively involving ships below 300 GT correspond to 3 % of the volume of operational spills (i.e. the spills discussed in Chapter 4 in this report). As a consequence, it is decided not to include the risk from accidents with small ships in the analysis.

3.2 General modelling

3.2.1 Fujii's model

In the present context, a model is understood to be a calculation method permitting to estimate the occurrence of shipping accidents based on basic data. The present section describes how accident frequencies are calculated by means of the established models. Observed data (such as traffic statistics) are used as input in the calculation.

A generally acknowledged method for estimating the frequency of accidents where ships run into some sort of obstacle – another ship, a ground, any other obstacle – was developed by the Japanese physicist Yahei Fujii (Fujii, 1984) and can be expressed in the following way:

$$F = N \times P_g \times P_c \times P_s$$

where

F ...	the accident frequency, i.e. number of accidents per year
N ...	the number of ship passages per year
P_g ...	the geometrical probability, i.e. the probability that a ship is on collision course with a nearby obstacle (within 20 ship lengths)
P_c ...	the causation probability, i.e. the probability that a ship on collision course does not undertake (successful) evasive action. This probability includes both human and technical failure.
P_s ...	the probability that the damage exceeds a certain limit, e.g. that the impact is violent enough to cause leakage

The modelling consists in calculating the above equation by determining the respective factors for each area and accident type. The aim is to describe the factors such that they describe the actual situation as well as possible. Because of its nature, this calculation will inevitably contain some uncertainty. However, experience shows that it can be useful, especially if the calculation is a good approximation that describes the occurrence of a phenomenon in a significant way for a given area.

Since Fujii's model gives a clear image of the influence of some of the most significant effects at question, choosing this model is a reasonable basis for establishing a more detailed model, as described in the following.

In the present risk analysis, the model is supposed to reflect the effect of risk-reducing measures (RRMs), which can be added by introducing an additional factor

P_e ...	Effect factor, which takes the effect of RRMs upon the causation factor into account (e.g. due to increased use of pilots)

and by adjusting the parameters of the traffic model in accordance with the expected effects of the RRMs (e.g. the fraction of ships using a maritime pilot, usage of ECDIS).

Fujii's model is used to calculate the occurrence of shipping accidents where ships run into an "obstacle" and is therefore linear dependent upon the traffic intensity N. In the case of collision between two ships, the collision frequency depends therefore upon the traffic intensity in both sailing directions. In order to be able to handle these accidents, Fujii's model is adjusted in such a way that the linear dependency on N is replaced by a function of the two colliding traffic intensities N_1 and N_2:

$$h(N_i) = \begin{cases} h(N) & \text{... for collision with fixed objects} \\ h(N_1; N_2) & \text{... for collision between ships} \end{cases}$$

Other parameters such as vessel speed, angles and lengths etc. are equally part of the calculation of the collision frequency (see Section 3.3).

The risk analysis of oil and HNS spill requires calculating the occurrence of the different incidents involving spillage depending on several conditions:

- Sea areas
- Substance groups for oil and hazardous substances, respectively
- Spill sizes
- Time-dependent scenarios (2024, 2036)

Therefore, Fujii's model needs to be generalised and expressed in such a way that the spills are assumed to occur at a series of representative locations:

F(location, substance group, spill size, scenario) = $h(N_i) \times P_g \times P_c \times P_s \times P_e$

3.2.2 General risk analysis model

With regard to the analysis of the different pollution events it is sensible to re-formulate Fujii's model such that

F{spill size} =

F{shipping accident} ×

P{hull damage with possibility for spillage | shipping accident} ×

P{spill size | hull damage with possibility for spillage} ×

Effect factor{Risk reducing measures}

where

F{spill size} is the spill frequency (occurrences per year). This quantity corresponds to *F* in Fujii's model.

F{shipping accident} is the frequency that a shipping accident that can cause spillage occurs. This quantity includes the effect of the traffic intensity (N, N_1 and N_2) in Fujii's generalised model), geometrical conditions with respect to route, vessel, speed etc. (P_g in Fujii's model) as well as navigational conditions (P_c in Fujii's model).

P{hull damage with possibility for spillage | shipping accident} is the probability of a shipping accident entailing a damage that breaks the containment of oil or hazardous substances and therefore can lead to an accident.

P{spill size | hull damage with possibility for spillage} is the probability of a given spill size in case of hull damage and can therefore be seen as being part of Fujii's factor P_S.

Effect factor{Risk reducing measures} is the reduction factor for the spill frequency that is estimated on the basis of the risk reducing measures

F{spill size} is then calculated for the same parameters as mentions above, i.e.

- Sea areas
- Substance groups for oil and hazardous substances, respectively
- Spill sizes
- Time-dependent scenarios (2024, 2036)

which can be expressed as

F{spillage | location, substance group, spill size, scenario}

It is emphasized that the above description is general so that variation will occur for the respective accident types – depending on the complexity of the respective problem. It can e.g. be necessary to calculate

P{hull damage with possibility for spillage | shipping accident}

and

P{spill size | hull damage with possibility for spillage}

as random distributions instead of probabilities. Details are not described here. In this way it becomes e.g. possible to handle the fact that a given spill size can consist of contributions both from minor spills from ships with a lot of cargo and from large spills from ships with less cargo.

3.2.3 Calculation procedure

The calculation of the spill frequencies is calculated based on the traffic model, which reflects the distribution of the ships with respect to

- vessel type
- vessel size, including size of the cargo tanks (tankers) and bunker tanks (all vessels)
- hull configuration (single/double)
- load state (loaded/in ballast)

- draught
- operational vessel speed
- risk-reducing measures (RRMs)

The traffic model has been prepared for traffic corresponding to the traffic in 2024 and 2036 (BRISK II, Traffic analysis, 2025). The models for the frequency of shipping accidents includes a number of risk reducing measures (RRMs), which are described in Section 3.9. Note, that some effects actually may increase the risk of accidents. Section 3.10 is dedicated to the risk-increasing effects specifically caused by the often poor characteristics of vessels belonging to the shadow fleet.

3.2.4 Distribution of leakage of oil and hazardous substances between substance groups

The methodology described above allows calculating the frequency of spills of different spill sizes (measured in tonnes). In a final step, the type of the spilt substance needs to be determined. This information is provided by the cargo model (BRISK II, Cargo analysis, 2025), which predicts the substance(s) on board a ship based on the ship type, ship size, sailing direction and sea area.

3.3 Ship-ship collisions

This chapter deals with collisions between two moving ships. Collisions between a moving ship and a stationary object (fixed structure or stationary ship) are dealt with separately in Chapters 5 and 6.

3.3.1 Collision frequency

The collision modelling is based on the route-based traffic model described the traffic analysis report (BRISK II, Traffic analysis, 2025).

Frequency of route collisions

Collision frequencies for route collisions (also called parallel collisions) are modelled for two situations (Figure 3-5):

- head-on collisions between ships sailing in opposite directions
- overtaking collision between ships sailing in the same direction

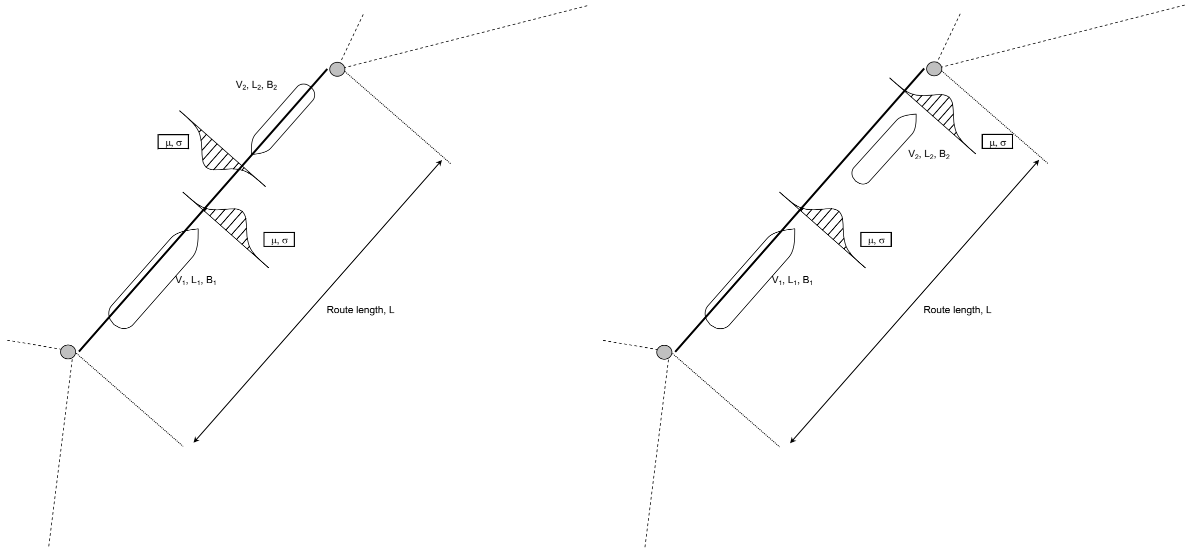


Figure 3-5 *Head-on and overtaking collisions*

The collision frequencies depend on:

- the length of the route segment
- the traffic intensity in each direction
- the length, breadth and speed of the ships
- the deviation of the ships from the route axis
- the causation probability P_c

Appendix A describes the applied model in more detail.

With the detailed route and traffic description described in the traffic analysis report, it is possible to calculate the collision frequencies for the respective route segments.

Frequency of node collisions

The frequencies of node collisions (also called crossing collisions) are modelled for a number of relative manoeuvres between the crossing ships. Figure 3-6 shows four important crossing manoeuvres.

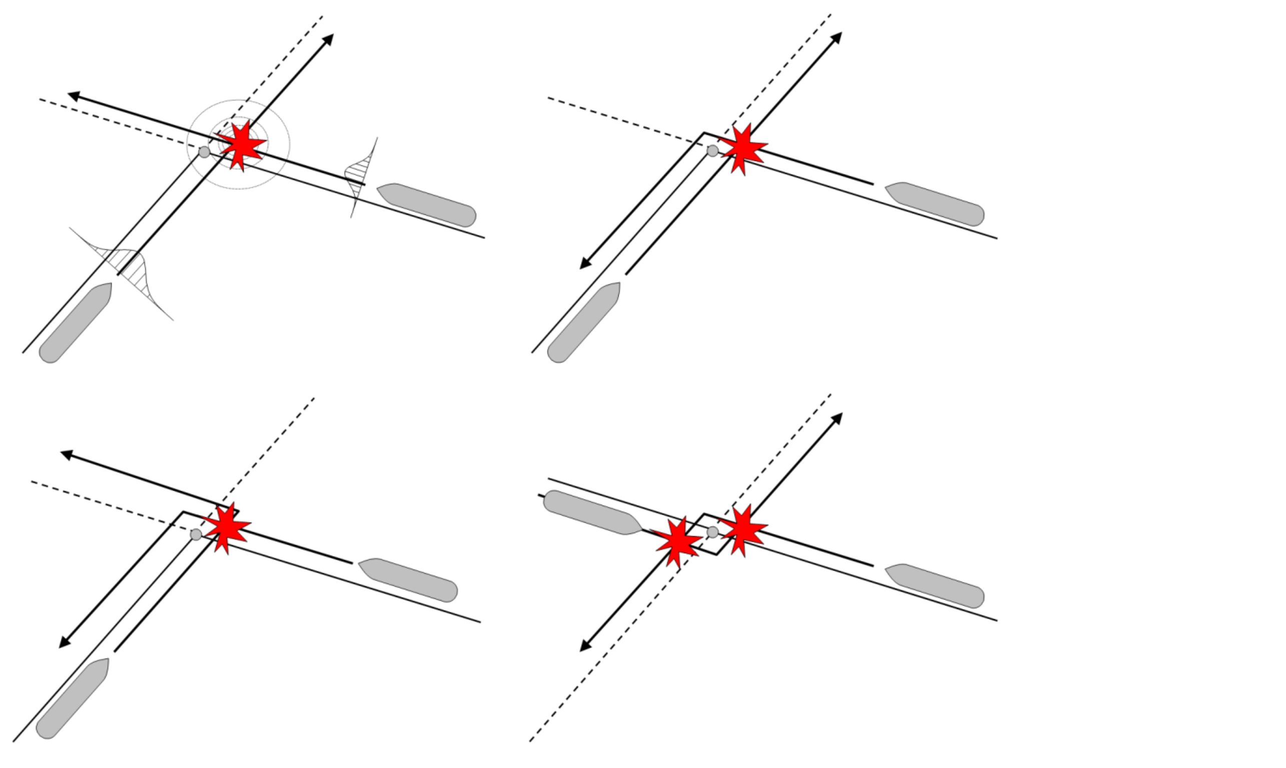


Figure 3-6 *Regular crossing collisions and bending/crossing collisions*

The collision frequencies depend on

- the traffic intensity in each direction
- the length, breadth and speed of the ships
- the crossing angle
- the causation probability P_c

Appendix A describes the applied model in more detail.

Based on the detailed route and traffic description described in the traffic analysis report, it is possible to calculate the collision frequencies for the nodes in the route net.

Model adjustment

Following the establishment of the collision model, the model needs to be calibrated. This is done by comparing the calculated number of collisions (based on the methodology described in this section) and the historical number of accidents described in Section 3.1. The calibration is described in deliverable D2.6 *Probability of oil and HNS release* (BRISK II, Prob. of release, 2026).

3.3.2 The effect of sea ice upon collision frequencies

The effect of sea ice during winter is to a large extent taken into account by the traffic model, which is one of the main input parameters of the collision model. Amongst other effects, sea ice influences the traffic intensity on the respective routes as well as the spreading of the traffic with respect to the route axis (see part 1 of the Model report).

However, there are also some effects that cannot be modelled by the season-specific traffic model input alone:

- Node collisions are much less likely in a situation where much of the traffic is sailing in convoys behind ice breakers. This circumstance can be considered either by modelling ship traffic in time domain or by reducing the causation factor significantly. However, it is chosen not to take any action in the present case. The results from BRISK I (BRISK I, Spill, 2012) showed that node collisions do not govern the result in ice-prone areas, with the exception of the traffic intersection halfway between Helsinki and Tallinn in the middle of the Gulf of Finland. Not correcting the node collision frequency is therefore a conservative model decision.

- Route collisions of ships going in the same direction are more likely due to ice-breaker convoys. This effect is modelled by a separate risk factor, see Section 3.9.10.

Figure 3-7 and Figure 3-8 illustrate the difference in collision frequencies during ice season and ice-free season according to the traffic model for the northern part of the Baltic Sea as estimated by BRISK I (BRISK I, Spill, 2012).

In the Bothnian Bay (Figure 3-7), the location and frequency of the expected collisions differed significantly between the two seasons. On one hand, this difference reflects the difference in traffic pattern during ice conditions. On the other hand, operating in narrow ice channels heightens the probability of route collisions.

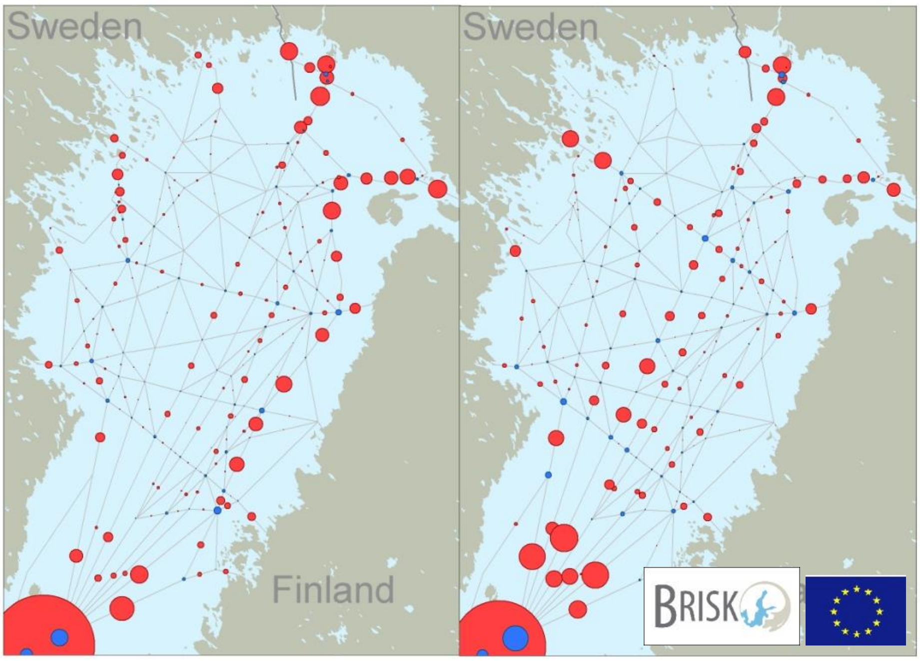


Figure 3-7 *Probability of route collisions (red) and node collisions (blue) in the Bothnian Bay, comparison between ice season (left) and ice-free season (right) (BRISK I, Spill, 2012). Probability is proportional to the area of the circles.*

In the case of the Gulf of Finland (Figure 3-8), two opposed trends were identified during BRISK I:

- On the main route along the centre line of the Gulf of Finland, collision frequencies were estimated to be higher during ice season due to the risk of collisions between the members of an icebreaker convoy. Note, however, that these accidents do not tend to be as violent as classical head-on or node collisions. Still, there is a real risk of spill, see also Section 3.9.10.
- Off the main route, collision frequencies are mostly reduced during ice season due to the lower number of ship passages relative to the ice-free season. In the case of Helsinki, an interesting double-effect can be seen: While collision frequency estimates decreased during ice season for ships to and from the downtown ports, they actually increased for ships to and from the Vuosaari harbour in the east.

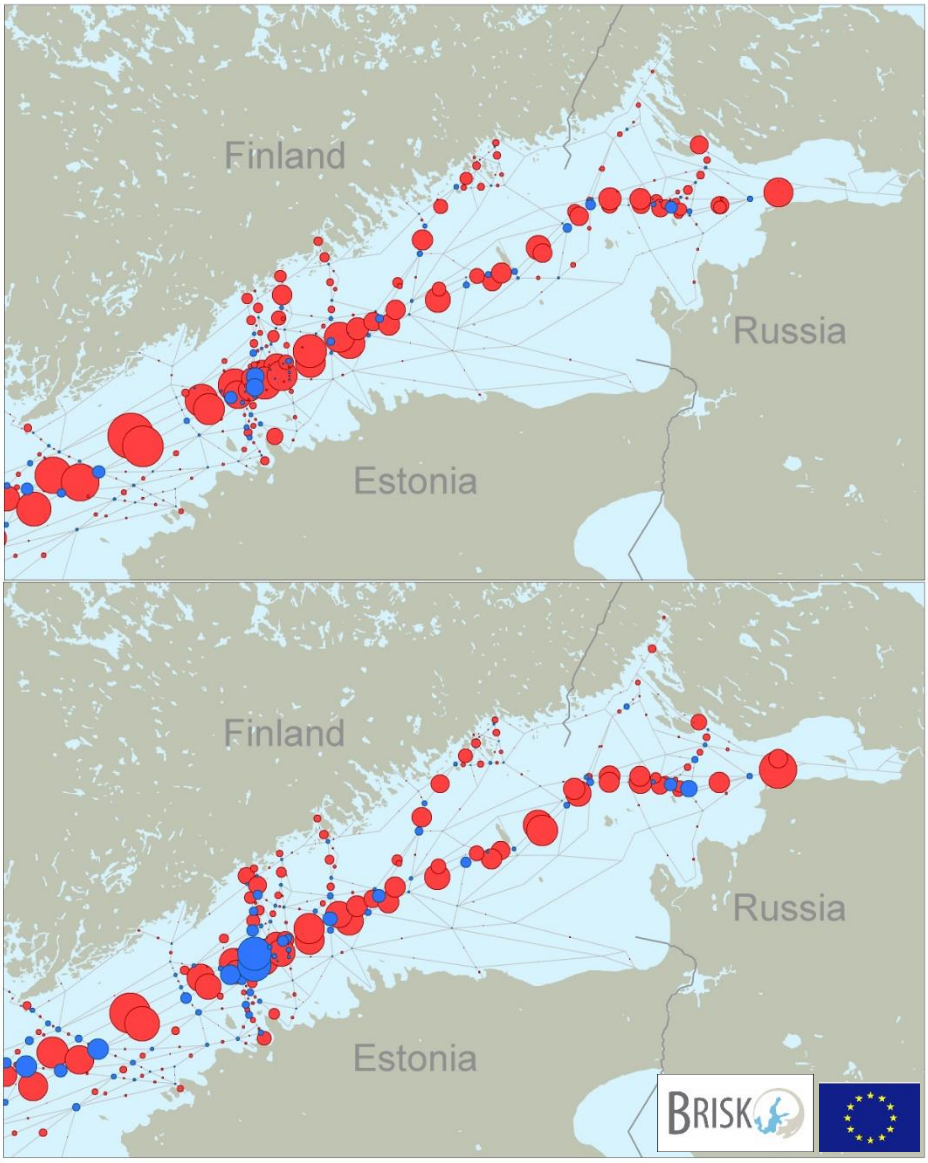


Figure 3-8 *Probability of route collisions (red) and node collisions (blue) in the Gulf of Finland, comparison between ice season (top) and ice-free season (bottom) (BRISK I, Spill, 2012) . Probability is proportional to the area of the circles.*

In numbers, the Bothnian Bay was estimated to experience 17 % more collisions per sailed nautical mile under ice conditions compared to ice-free conditions. In the Gulf of Finland, 9 % more collisions were estimated.

These results can be held up against the observed pattern among historical collisions north of the 59° parallel (i.e. latitude). Despite of the small total number of collisions, Figure 3-9 seems to illustrate that the actual collision frequency could be as much as five times higher under ice conditions compared to ice-free conditions. This difference is significantly larger than what the model indicates. Hence, an increased risk in icebreaker convoys is modelled, see Section 3.9.10. It should be noted that two additional ship–ship collision records could not be included in the monthly statistics because the accident date is missing. All three of these excluded cases involved icebreakers. In addition, one icebreaker-related collision with complete date information is included in the statistics and occurred in February.

In fact, no presently existing model is capable of describing the entire range of ice-related phenomena. However, it is possible to introduce a correction factor based on the statistical evidence. At the moment, the model is calibrated to the overall collision statistics, i.e. without taking seasonal differences into account. A seasonal correction factor can be introduced at any time.

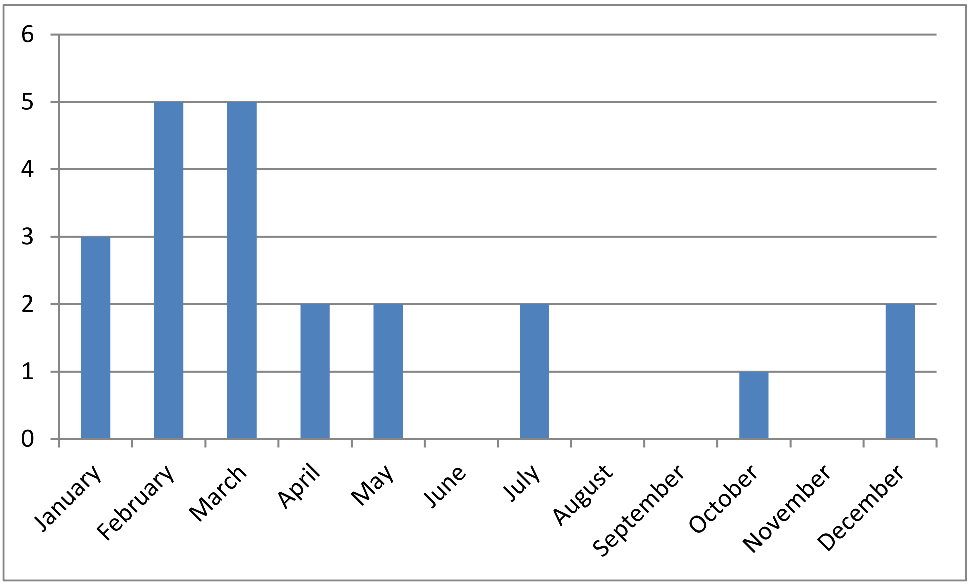


Figure 3-9 *Relevant ship-ship collisions north of the 59° parallel, 2015-2024*

3.3.3 Collision consequences

Hull damage in case of collision

In order to assess the consequences of ship-ship collisions, a series of idealised ship designs have been developed. The damage size in case of a collision is described in accordance with work performed by Erik Sonne Ravn and Peter Friis-Hansen at the Technical University of Denmark, who elaborated routines simulating large numbers of representative collision scenarios. Hull damage was modelled by means of finite-element analysis for a number of ship-ship combinations. The results were used to train a neural network that was then used to predict the hull damage for a much larger number of ship-ship combinations. The model is able to determine

- the penetration at the struck vessel (both for bulb-shaped and conventional ship bows)
- the damage length at the struck vessel
- the damage height at the struck vessel
- the vertical position of the damage

These results are calculated based on data about the colliding ships:

- vessel speeds
- collision angle and draught
- bow shape (bulb or conventional)

The results from these simulations are used to estimate the possible spill in case of collision.

The collision consequence model includes 600 representative ships of various types and sizes.

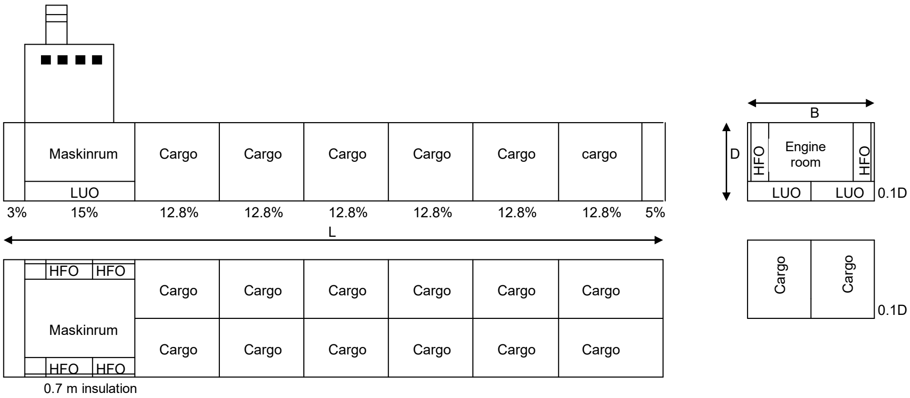
Spill in case of hull damage

A number of assumptions need to be made to determine the amount of bunker oil and eventual cargo emerging in case of hull damage:

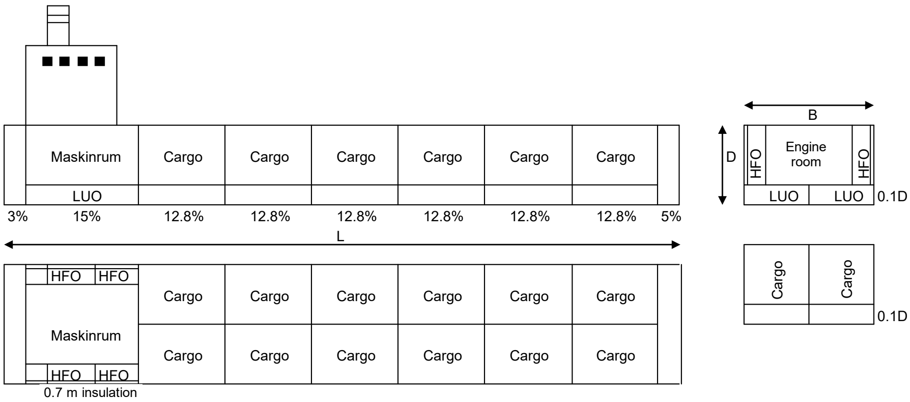
- Selection of a representative ship: Each of the 7,000+ ships in the traffic model is assigned to one of the 600 representative ships
- Size of the bunker tank
- Division into cargo compartments of equal size
- Triangular distribution of the collision speed from 0 to v_{max} with 2/3 v_{max} as the most probable case
- Collision angles in the interval 30 to 150° *(Note: The specific case of route collisions, i.e. collisions typically occurring at 0° or 180°, is discussed at the end of this section)*

- Ship types are represented by rectangular boxes with rectangular cargo compartments, i.e. as idealised vessels (Figure 3-10 illustrates the case of tank ships):

Single hull



Single hull with double bottom



Double hull

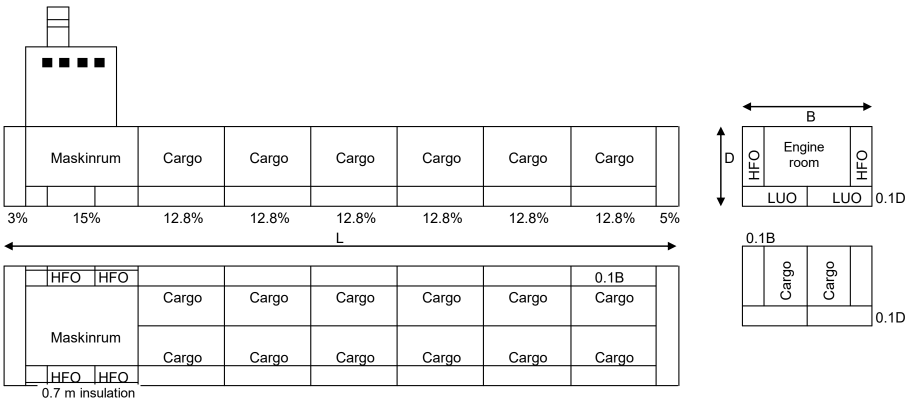


Figure 3-10 Idealised tankers used for determining the spill in case of hull damage (HFO = heavy fuel oil, LUO = lubricating oil)

The spill size depends on the position of the damage relative to the water line:

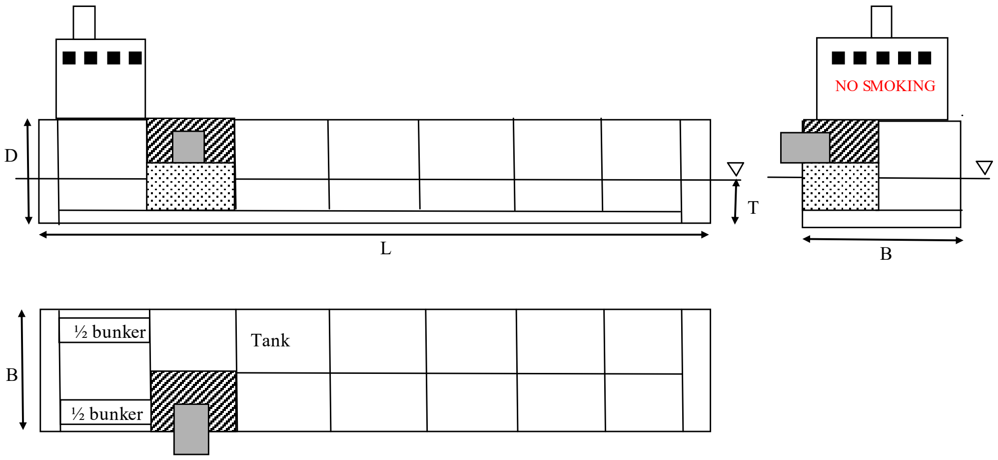


Figure 3-11 *Example of a penetration above the water line. The shaded part is leaked. The dotted part remains in the tank.*

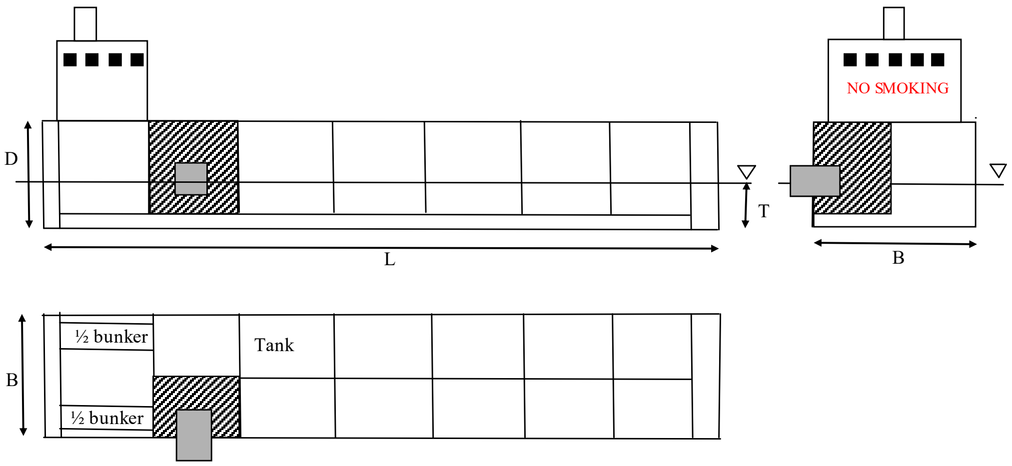


Figure 3-12 *Example of a penetration below the water line. The entire shaded part is leaked.*

For each collision, 250 simulations with varying angles, collision point relative to the ship length and speed are performed. Cargo and bunker spills from each simulation are classified according to the intervals shown in Table 3-5. For each interval, a probability is indicated.

Table 3-5 Relative spill intervals for which the respective probabilities are calculated in the simulation

Cargo spill size classes (percentage of cargo capacity)	Bunker spill size classes (percentage of bunker capacity)
<0.1% (no spillage)	<0.1 %(no spillage)
0.1-6 %	0.1-17%
7-11 %	18-25 %
12-17 %	26-33 %
18-33 %	34-50 %
34-50 %	51-100 %
51-100 %	

The spills are calculated for a number of different scenarios, where

- the striking ship is
  - loaded/not loaded
  - hitting diagonally from the front/back

- the struck ship is
  - loaded/not loaded
  - double-hulled/single-hulled
  - bunker-protected (double hull at bunker)/not bunker-protected

In addition, all combinations between the representative ships used in the simulations are analysed. This yields a very large number of combinations (>300,000).

Considerations regarding route collision consequences

With respect to the consequences of route collisions, some adaptations to the above-described model are made. In general, the model implies that ships do not penetrate each other, if the collision occurs at a very acute (<30°) or very obtuse angle (>150°). Instead, they just grind alongside. This, however, does not mean that parallel collisions are by any means harmless:

- Routes are an idealisation of reality. In many cases, ships that have been allocated to one route leg in the traffic model do not move perfectly parallel in reality.

- Two ships in a head-on situation having failed to make an evasive manoeuvre in good time will typically try to change their direction as a last resort prior to impact. This means, that one or both ships are likely to “open up” and present their side to the other ship. If the evasive manoeuvre fails, one of the two ships will be struck in a vulnerable constellation (angel between 30° and 150°).

- In an overtaking situation, it is less likely that a ship "opens up" than with head-on situations. Assuming that this behaviour nevertheless occurs in 10 % of all cases was deemed to be very conservative by the nautical experts consulted during an earlier analysis (Bornholmsgat, 2008). This conservative assumption is used for the BRISK II model.

3.4 Groundings

3.4.1 Grounding frequency

Approach

The approach for calculating the grounding frequency is simple and based upon the available data and statistics.

1. In the cargo analysis (BRISK II, Cargo analysis, 2025), the Baltic Sea has been divided into several traffic areas. For each of these areas, a number of representative grounding points (grounding locations) are identified.

2. For each traffic area, the grounding frequency is calculated, based on historical accident data and divided with the number of nautical miles sailed per year. The result is a grounding frequency per sailed nautical mile. Each traffic area has a different frequency.

3. The grounding frequency is corrected for the effect of risk reduction measures (RRMs, see Section 3.9) in order to obtain a "basic" grounding frequency per sailed nautical mile.

4. Present and future grounding frequencies are calculated on an annual basis by multiplying the distance sailed by different ships with the basic grounding frequency per nautical mile and with various risk-reducing factors representing the effect of the RRMs. This step is performed separately for each ship type and ship size, since not every ship is subject to the same RRMs.

The approach is described in more detail in Appendix B.

Table 3-6 presents the raw grounding frequencies in the different traffic areas, derived directly from the statistical observations. The determination of basic grounding frequencies, corrected for the effect of risk-reducing measures, requires the calibration method described in Appendix B, Section B.4. As this procedure depends on calculated model results, the corresponding corrected grounding frequencies will be established and presented in deliverable D2.6 (BRISK II, Prob. of release, 2026).

Table 3-6 Raw grounding frequency

Cargo area	Raw grounding frequency per mile (incl. RRMs)
1 Bothnian Bay	2.42×10^{-7}
2 Bothnian Sea and West of Gotland	4.58×10^{-7}
3 E Gulf of Finland[3]	5.69×10^{-8}
4 W Gulf of Finland and Klints Bank	5.69×10^{-8}
5 E Baltic Proper	1.07×10^{-7}
6 South of Gotland	3.06×10^{-8}
7 Slupsk Bank	8.25×10^{-8}
8 Baltic Sea Entrance and Arkona Sea	3.42×10^{-7}
9 Kattegat	5.01×10^{-7}
Total[4]	2.41×10^{-7}

3.4.2 The effect of sea ice upon grounding frequencies

Grounding frequencies per nautical mile are calculated separately for the ice season and the ice-free season for traffic areas that are regularly affected, i.e. the north of the 59° parallel. It is found that grounding frequencies per nautical mile are elevated by 30 % during ice season and reduced by 10 % during ice-free season compared to the whole-year average. In other words, sailing in ice conditions is observed to be 42 % more likely to result in a grounding than sailing under ice-free conditions. Note however, that the definition of "ice" and "no ice" is attached with some uncertainty. The local ice situation has not been verified for every single event (see Appendix B for more detail).

The effect of sea ice during winter is furthermore taken into account by the traffic model, which is one of the main input parameters of the grounding model. Amongst other effects, sea ice influences the traffic intensity on the respective routes (BRISK II, Traffic analysis, 2025).

[3] Based on W Gulf of Finland and Klints Bank due to lack of area-specific information

[4] E Gulf of Finland not included in the sum due to lack of area-specific information

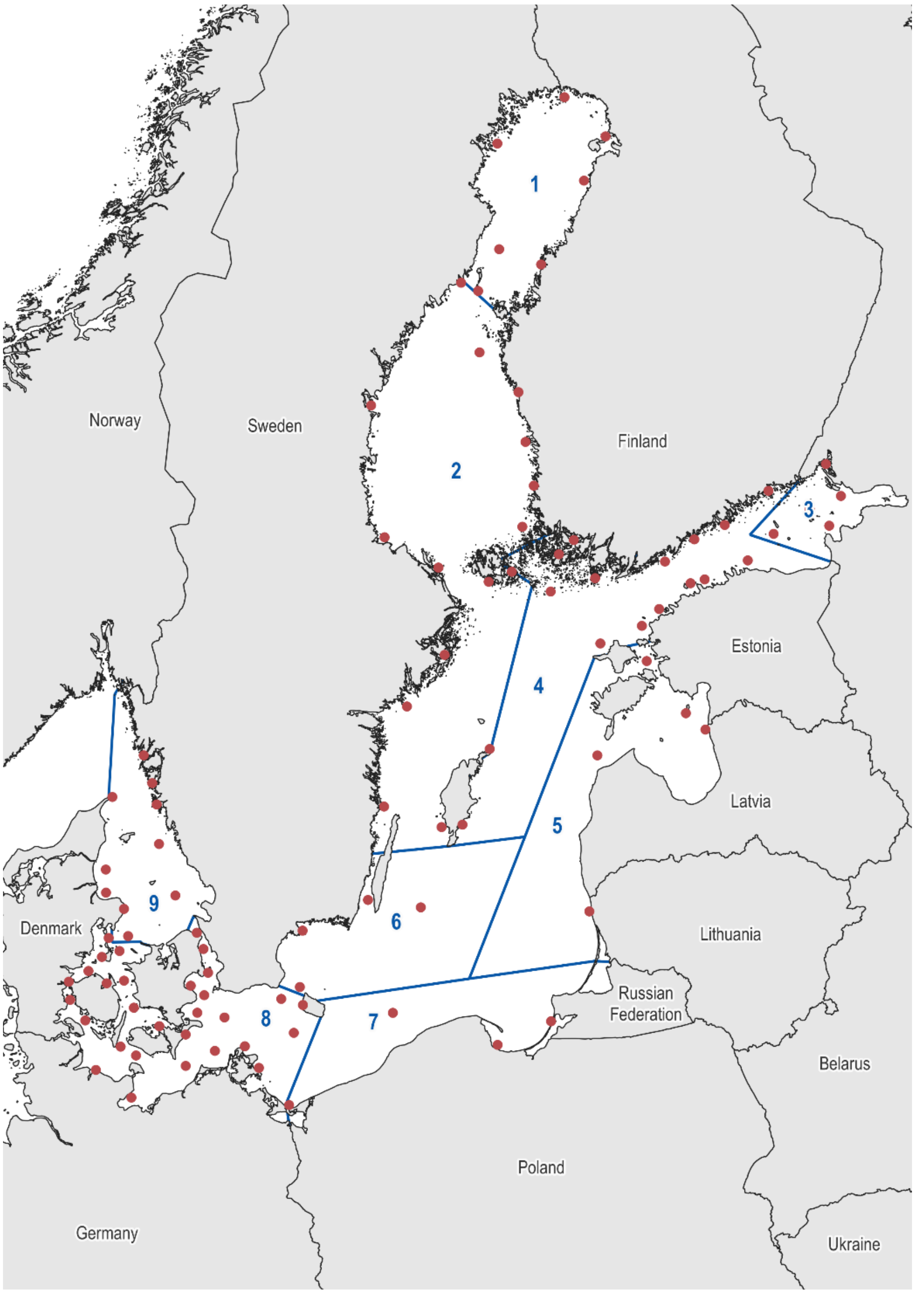


Figure 3-13 *Location of the representative grounding points*

3.4.3 Grounding consequences

Probability of spill in case of grounding

The probability and quantity of spill in case of grounding is derived from the results in (Rømer, 1996). Separate models are indicated for cargo and bunker spillage, respectively.

Cargo spill

Rømer (Rømer, 1996) proposes a spill probability of 0.25 in case of a grounding for single hull tankers. A recent analysis performed at Aalto University in Espoo, Finland supports this number (Ylitalo et al., 2010). As in (Oil spill DK, 2007), a value of 0.15 is chosen for the specific case of soft grounds. With rocky grounds, a value of 0.3 is chosen, which is also in agreement with (DNV, 2003).

In the case of double-hull tankers, (Rømer, 1996) proposes a spill probability of 0.03 in case of a grounding. The earlier Danish analysis (Oil spill DK, 2007) utilised a value of 0.02, which is reasonable considering the prevailingly soft Danish grounds. The BRISK II model uses the same number for soft grounds. In the case of rocky grounds, a value of 0.06 is chosen based on numerical simulations at Aalto University in Espoo, Finland (Ylitalo et al., 2010).

The used probabilities of cargo spill in case of grounding are indicated in Table 3-7 below.

Table 3-7 Probability of cargo spill in case of grounding

Vessel type	Ground type	*P{cargo spill | grounding}*
Single hull cargo ship (bulk)	Soft	0.15
	Rock	0.30
Double hull cargo ship (bulk)	Soft	0.02
	Rock	0.06
Not loaded ships	Soft/Rock	0.00
Ships carrying packed goods (containers, general cargo, Ro-Ro)	Soft/Rock	0.00

Bunker spill

In (Oil Spill DK, 2007), a general bunker spill probability of 0.01 in case of grounding of a loaded ships is used. This number is adapted to the Danish situation with prevailingly soft grounds. Michel and Winslow (Michel & Winslow, 2000) calculate the probability as 0.01 to 0.08 for container ships and bulk carriers, and 0.22 for loaded very large crude carriers (VLCCs). However, some of these model-based results appear rather high when taking the actual accident statistics into account (see Section 3.1) as well as the probability of cargo spill in case of grounding (see above).

The used probabilities of bunker spill in case of grounding are indicated in Table 3-8. The numbers are based on engineering judgement and apply only to loaded vessels. Grounding of unloaded vessels is unlikely to result in a major bunker spill. This is due to geometrical reasons (less draught in combination with the fact that bunker tanks are usually located at the rear of the ship) and the fact that the vertical forces between the ship and the ground are lower, if the ship is not loaded.

Table 3-8 Probability of bunker spill in case of grounding of a loaded ship

Vessel type	Ground type	Bunker protection	*P{bunker spill | grounding}*
All	Soft	Yes	0.01
		No	0.02
	Rock	Yes	0.05
		No	0.10

Spill size

Also here, separate models are indicated for cargo and bunker spillage, respectively.

Cargo spill
Two scenarios are used:

Scenario 1:
Spill of less than 100 t cargo: *P{scenario 1 | spill single hull}* = 0.974

P{scenario 1 | spill double hull} = 0.94

Scenario 2:
Spill of more than 100 t cargo: *P{scenario 2 | spill single hull}* = 0.026

P{scenario 2 | spill double hull} = 0.06

In Scenario 1, the spill is set to either 30 t or 0.1 % of the cargo, whichever is less. In this way, ships with a DWT of less than 30,000 t are assumed to spill less than 30 t and the other ships are assumed to spill 30 t.

The spillage in Scenario 2 is distributed as in Table 3-9.

Table 3-9 Probability distribution for the fraction of the cargo spilt in case of a tanker, bulk carrier or other loaded ship running aground (only spills larger than 100 t). Source: CHEMAX

Spilt fraction of the total cargo in case of a grounding accident	Probability
5 %	0.5000
15 %	0.2500
25 %	0.1250
35 %	0.0625
45 %	0.0313
55 %	0.0156
65 %	0.0078
75 %	0.0039
85 %	0.0020
95 %	0.0020

Bunker spill
There is a difference between the actual bunker tanks (fuel for vessel propulsion) and the smaller lubricant tanks, since the regulations for double-hull at bunker tanks (cf. Section 3.9.8) do not apply to lubricant tanks. A part of the presently existing vessels are equally double-hulled next to the bunker tanks, but not next to the lubricant tanks. In the analysis of spill consequences, no difference is made between oil

bunker and lubricant spillage, since both substances are covered by the same goods group in the goods transport model (compare part 2 of the Model report).

The bunker spill size model shown in Table 3-9 has been chosen to be the same as in (Oil spill DK, 2007). A spill of 0 to $^{1}/_{200}$ of the total bunker capacity corresponds to a leakage of the lubricant tanks. Spill between $^{1}/_{6}$ and $^{1}/_{2}$ is not considered very probable and therefore not modelled in a separate scenario.

Table 3-10 Probability distribution for the fraction of the bunker fuel spilt in case of a grounding

Expected fraction of total bunker volume released in case of a leakage	General cargo and Roro ships incl. work vessels and RoPax ferries		Oil and chemical tankers, bulk carriers, container ships
	Single hull at the bunker tanks	Double hull at the bunker tanks	Double hull at the bunker tanks
0 to 1/200 (0-0.5 %)	0.0	0.875	0.875
0 to 1/6 (0-17 %)	0.95	0.11875	0.11875
1/2 to 1/6 (18-50 %)	0.05	0.00625	0.00625

Ground properties

Winterhalter et al. (Winterhalter, 1981) provide information on the ground properties in the Baltic Sea. The model uses this information to determine the likelihood of meeting soft or rocky ground in case of groundings at a specific location.

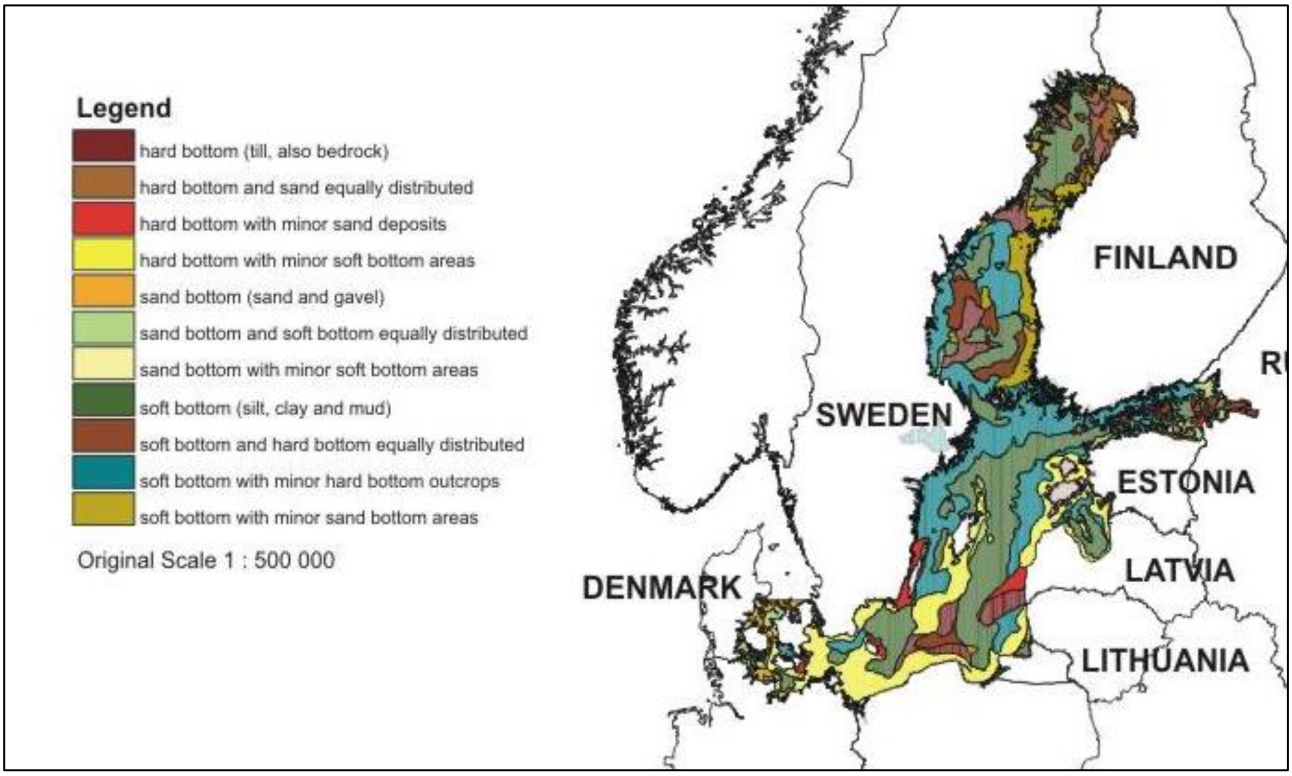


Figure 3-14 Geology of the Baltic Sea (Winterhalter, 1981)

3.5 Fire and explosions

Frequency of fire and explosion events

57 cases of fire on board were registered during the observation period 2015-2024, corresponding to 5.7 fires per year (compare Table 3-2). These numbers refer to events outside ports with ships of 300 GT and above. During the reference period, i.e. 1 Jan 2024 to 31 Dec 2024, the total sailed distance in the project area with ships matching the same criteria amounted to 48.5 million nautical miles. This corresponds to 1.18×10^{-7} events per sailed nautical mile.

Out of the 57 events, 3 were linked to oil or chemical tankers, i.e. 0.3 per year. With 87.3 million nautical miles per year sailed with tankers in the project area during 2024, this corresponds to 3.02×10^{-8} events per sailed nautical mile, which is significantly lower than the average value for all ship types.

An earlier investigation by DNV (DNV, 2003) used a frequency of 1.5×10^{-8} fire events per sailed nautical mile in one of the cargo compartments of a tanker. This number is lower by a factor of eight, which can be explained by the fact that only a small part of all fires involves the cargo compartment. Obviously, fire in one of the cargo compartments is a rare event that has not been observed in the Baltic Sea during 2015-2024.

The frequency of fire and explosions is thus estimated as

P{Fire in cargo compartment of a tanker} = 1.5×10^{-8} / nautical mile sailed with tankers

Consequences of fire and explosions

It is assumed that

P{Spill | fire in a cargo compartment of a tank ship} = 1.0

The probabilities of relative spill sizes are derived from (DNV, 2003) and (Oil spill DK, 2007) and are indicated in Table 3-11.

Table 3-11 Probabilities of the relative spill sizes in case of fire aboard a tanker

Spill size	Probability
0-0.1 % of the cargo	0.12
0.1-0.4 % of the cargo	0.24
0.4-12 % of the cargo	0.58
12-100 % of the cargo	0.06

3.6 Collisions with offshore wind farms

3.6.1 Introduction

Several offshore wind farms (OWFs) will be constructed between the reference year 2024 and the prognosis year 2036, see Figure 3-15. Routes intersecting planned OWFs are coloured red, whereas routes intersection potential OWFs (i.e. OWFs that have not been approved by the authorities yet) are not highlighted. Potential OWFs are only shown for information purposes but not considered in the model.

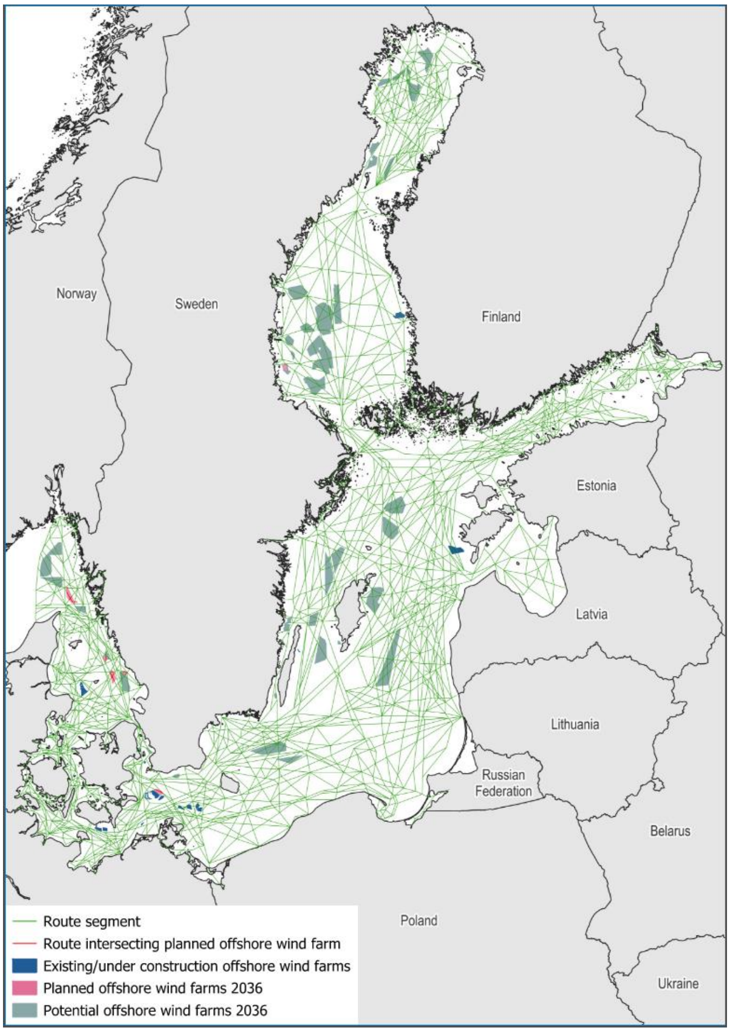


Figure 3-15 Offshore wind farms, existing in 2024 (blue) and planned for construction before 2036 (pink). Potential offshore wind farms are equally shown in the figure (green) but not taken into account in the 2036 model.

3.6.2 Risk of spill

The primary identified hazard is the risk of oil spills following a collision between a passing vessel and an offshore wind farm.

The risk of oil spills due to ship collisions against offshore wind turbine is analysed in detail in Appendix D. The analysis of the ship impact frequency is based on Fujii's model (see Section 3.2.1) in combination with other considerations and previously existing risk analyses.

3.7 Collisions with other fixed objects than wind farms

A number of fixed objects can be found at the open sea. In the method note (BRISK II, Method note, 2025), the following types of fixed objects have been defined as part of the scope:

- Large buoys and at-sea lighthouses
- Offshore oil installations
- Other (no relevant objects identified)

If a ship hits an offshore oil installation, oil can leak both from the installation and from the involved ship. It is estimated the spill risk related to the platform clearly dominates over the spill risk related to the involved ship. Therefore, the spill risk from the ship hull is not modelled.

The risk of an oil release from a loading buoy hit by a ship is modelled in Section 5.3.

The risk of an oil release from a platform hit by a ship is modelled in Chapter 6.

3.8 Capsizing and other potentially polluting accidents

3.8.1 General considerations

Other accidents than those described above can also be the cause of a spillage. During 2015-2024, four such accidents have been recorded (compare Table 3-2). They included 3 cases of damage to ship or equipment and 1 case of capsizing. For two of the cases, the causes are specified and relate to hard weather conditions and lacking routines, respectively.

Damage to ship or equipment

Three events:

- General cargo vessel, approx. 3,000 GT. Loss of port anchor attributed to hard weather conditions. No pollution reported.
- Bulk carrier, approx. 35,000 GT. anchor failure (anchor broke in two). No pollution reported.
- Container vessel, approx. 10,600 GT. Damage to both anchors. No pollution reported.

Capsizing

One event:

- Barge, approx. 1,200 GT. Capsizing/listing event caused by lacking routines and hard weather conditions. The hull was severely damaged and minor pollution of plastic (styrofoam) was reported.

Conclusions

Spill from physical damage which has not been caused by other accidents (grounding, collision, fire) is considered to be relatively insignificant. Therefore, the model only takes Capsizing into account.

3.8.2 Modelling

Frequency

One Capsizing events during 2015-2024 correspond to 0.1 occurrences per year. With regard to the yearly traffic 48.5 million nautical miles sailed in 2024, this corresponds to 2.06×10^{-9} occurrences per nautical mile. For comparison, BRISK I reported a rate of 6.5×10^{-9} events per sailed nautical mile, which is about three times higher.

Due to the small number of events (one in ten year), it is decided to use the occurrence rate from BRISK I, which was based on two events within five years. The frequency of foundering is therefore modelled as

$$P\{Foundering\} = 6.5 \times 10^{-9} \text{ / nautical mile sailed}$$

It is noted that the recorded capsizing cases all involved small vessels. Using an estimated frequency derived for all ships, including large vessels, may therefore lead to an overestimation of the potential spill sizes.

Consequences

The probability of spill in case of foundering is estimated as

$$P\{Spill|Foundering\} = 0.5$$

The size of the spill relative to the cargo and bunker capacity of the respective ship is estimated as

Spill size = 50-100 % *of the cargo/bunker volume (uniformly distributed)*

3.9 Preventive risk-reducing measures

The accident model components described earlier in this chapter treat all vessels in an idealised way that ignores many ship-specific and regional characteristics. Most of these characteristics have a risk-reducing effect, whereas some others can lead to additional risk. This section describes the most relevant preventive risk-reducing measures (RRMs) and the way they are modelled. Relevant phenomena that are increasing risk are equally described.

The effect of the respective RRMs is expressed by means of a risk reduction factor. A risk reduction of e.g. 20 percent means that the risk is reduced to 80 percent of its initial value and corresponds to a risk reduction factor of 0.8.

3.9.1 Pilotage

Fraction of affected ships

The fraction (percentage) of ships using a pilot depends on the area they are sailing in, the sailing direction, the load state, the ship type and the ship size. The pilotage percentage is described in Appendix C.

Effect

It is difficult to quantify the risk-reducing effect of having a pilot on board. The effect is situation-dependent in many different ways and subject to phenomena that are difficult to model.

However, an analysis of data from different parts permits some basic conclusions. The analysis in (Lentz & Kroon, 2010) is based on areas, where pilotage is officially recommended but not compulsory. In this way, it has been possible to compare the accident rate of the same type of ships at the same location both with and without a pilot. The analysis shows that a risk-reducing factor of 0.33 is a conservative assumption. This number means that ships with a pilot are estimated to be three times less likely to be involved in collisions and groundings than ships without a pilot.

In very demanding sections, pilots can have a very strong effect corresponding to a risk reduction factor of approximately 0.1. This factor is used for the Drogden channel in the Sound.

3.9.2 VTS centres

Vessel traffic service (VTS) centres are on-shore traffic surveillance centres enhancing navigational safety in critical areas. Their main interventional tools are warnings and advice to passing vessels.

Affected areas

There is VTS coverage in the following major areas:

- Great Belt (Denmark)
- The Sound (Denmark and Sweden)
- Gulf of Finland (GOFREP and national coastal VTS areas – Estonia, Finland and Russia)
- Archipelago Sea (Finland)
- Finnish west coast (i.e. the eastern shore of the Gulf of Bothnia)
- Apart from the Sound (together with Denmark), Sweden operates nine local VTS centres, typically covering the coastal zones close to the major ports
- Germany operates two VTS centres in the Baltic Sea covering the coastal zones close to its main ports.
- Latvia operates three VTS centres covering the coastal area close to the ports of Riga, Ventspils and Liepaja.
- Poland operates two VTS centres covering the Gdansk Bay and the Pomeranian Bay.

Effect

VTS centres are modelled with a risk factor of 0.5, i.e. a 50 percent risk-reducing effect upon unpiloted vessels with respect to collisions and grounding. The effect upon piloted vessels is modelled with a risk factor of 0.95, corresponding to a 5 percent risk reduction.

3.9.3 Traffic separation schemes (TSS)

Locations

All currently existing traffic separation schemes are included in the analysis. Sea areas that are located between two TSS are equally modelled as TSS, if the traffic pattern observed via AIS resembles the traffic in a TSS.

Effect

Traffic separation schemes have primarily an effect upon route collisions, i.e. head on and overtaking collisions. The AIS-based traffic model reflects the effects of the TSS. In this way, the risk-reducing effects are automatically taken into account by Fujii's model described in Section 3.3.1.

3.9.4 Electronic Chart Display and Information System (ECDIS)

Affected ships

Since 1 July 2018 (IMO, 2009), ECDIS has been obligatory

- for all passenger ships of 500 GT and upwards
- for all tankers of 500 GT and upwards
- for all cargo ships other than tankers of 10,000 GT and upwards
- for all cargo ships other than tankers of 3,000-9,999 GT, if they are constructed on or after 1 July 2014

It can be expected that some of the smaller vessels that are not affected by the new IMO rules will be equipped with ECDIS on a voluntary basis. This possibility is disregarded, which is a conservative simplification.

Effect

ECDIS has a risk-reducing effect primarily affecting the possibility of groundings. It is estimated to reduce the grounding proneness of a ship by 50 percent, if the ship is unpiloted and sailing in an area without VTS coverage (risk reduction factor of 0.5). If a pilot is onboard or VTS coverage is available, the risk is estimated to be reduced by only 5 % (risk reduction factor of 0.95).

3.9.5 Bridge Navigational Watch Alarm System (BNWAS)

BNWAS is a system that strikes alarm, if no signs of human activity are registered on the bridge of a ship.

Fraction of affected ships

In the years between 2011 and 2014, a set of IMO rules concerning BNWAS gradually came into force (IMO, 2009). Since 1 July 2014, BNWAS has been be obligatory

- for all passenger ships irrespective of size
- for all cargo ships of 150 GT and upwards

Considering that the BRISK II model only regards ships of 300 GT and upwards this means that all ships within the scope of the analysis will be affected by the new IMO rules.

Effect

Since all relevant ships are affected by this risk-reduction measures, the effect of the measure is already included in the accident statistics that are used to calibrate the model. Thus, there is no need for a specific risk-reduction factor for BNWAS.

3.9.6 Alcohol limits

Fraction of affected ships

The Conference of Parties to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers limits the blood alcohol content of bridge personnel to 0.5 permille (SCTW, 2010).

Effect

Since all relevant ships are affected by this risk-reduction measures, the effect of the measure is already included in the accident statistics that are used to calibrate the model. Thus, there is no need for a specific risk-reduction factor for the 0.5 permille blood alcohol limit.

3.9.7 Double hull at the cargo tank

A double hull at the cargo tank reduces the risk of spill in case of grounding or collision.

Fraction of affected tankers of 5,000 DWT and more

According to the revised regulation 13G (regulation 20 in the revised Annex I which entered into force on 1 January 2007) of Annex I of MARPOL (IMO, 1987), single-hull tankers of 5000 DWT or more had to be phased out between 2005 and 2010. Thus, no medium-sized and large single-hulled tankers are expected to be in duty any longer. It has been checked whether there are any single-hull tankers among the shadow fleet, but there are none.

Fraction of affected tankers below 5,000 DWT

In 2008/2009, only around 3 percent of all smaller tankers were known to have been single-hulled. However, there was uncertainty about the hull status of around 23 % of the ships (BRISK I, Spill, 2012). During BRISK I, both tankers with known single-hull status and tankers without known hull status were counted as single-hulled, corresponding to a percentage of 26 % of all small tankers. For 2020, BRISK I assumed that 20 % of the small tankers would be single-hulled.

Based on the above, the following is assumed for BRISK II for small tankers under 5,000 DWT:

- 15 % of the tankers were single-hulled in 2024
- 10 % of the tankers will be single-hulled in 2036

Effect

The effect of double-hulled cargo tanks is implemented as part of the collision consequence model (Section 3.3.3) and the grounding consequence model (Section 3.4.3).

3.9.8 Double hull at the bunker

Fraction of affected ships

Regulation 12A, which is an amendment to Annex I of MARPOL (IMO, 1987) requires that all vessels with a bunker tank volume of 600 m^3 or more must be double-hulled at the bunker compartments

- if the building contract was placed on or after 1 August 2007
- or if the keel was laid on or after 1 February 2008
- or if the vessel was delivered on or after 1 August 2010

The 600 m^3 bunker capacity roughly corresponds to a 10,000 DWT vessel.

Back in 2007, the following was assumed based on estimates by the Danish Maritime Administration (Oil spill DK, 2007) for ships with 600 m^3 or more bunker capacity:

- By 2010, the fraction of ships with double-hulled at the bunker would be 10 percent
- By 2020, the fraction of ships with double-hulled at the bunker would be 50 percent

These numbers were also applied for BRISK I (BRISK I, Spill, 2012).

For the current situation, the following is assumed for ships with 600 m^3 or more bunker capacity based on the typical lifetime of ships:

- 2024: 60 %
- 2036: 80 %

Effect

The effect of double-hulled bunkers is implemented as part of the collision consequence model (Section 3.3.3) and the grounding consequence model (Section 3.4.3).

3.9.9 Escort towing in narrow shipping lanes

During escort towing, a tug is permanently connected to a tanker on its journey between the open sea and the port. Escort towing is especially relevant in very narrow shipping lanes.

Fraction of affected ships

Escort towing is presently common, recommended or obligatory in the following HELCOM countries:

- Finland: Escort towing is neither officially recommended nor obligatory. However, when BRISK I was carried out, escort towing was part of the policy of the largest Finnish oil company as far as loaded tankers are concerned (BRISK I, Spill, 2012). It was also known that there were too few tugs for servicing all tankers approaching or leaving the Finnish coast (VTT, 2002). On this basis, it was conservatively estimated that 20 % of all tankers of 20,000 DWT and upwards are using escort towing between the Finnish coast and the open sea. This assumption is assumed to be still valid for 2024 and 2036.

- Poland: Escort towing is obligatory at all ports and roadsteads, if certain wind conditions are present (BRISK I, Spill, 2012). In practice, this means that 10 % of all ships falling under the MARPOL convention are using escort towing. Since these operations mainly occur inside ports, they are not part of the BRISK II scope.

- Sweden: The authorities have issued a number of recommendations about the usage of escort towing. The recommendations apply

- in the Brofjorden: To all loaded and unloaded oil tankers (loaded/unloaded) of 20,000 DWT and upwards

- in the Stenungsund: To all loaded and unloaded oil and gas tankers (loaded/unloaded) of 20,000 DWT and upwards as well as all ammonia tankers

- in Göteborg: To all loaded and unloaded oil tankers (loaded/unloaded) of 30,000 DWT and upwards

Since there are no statistics on the usage of escort towing, it is assumed that 50 % of all affected ships comply with the recommendations.

Effect

The risk-reducing effect of escort towing affects primarily the risk of groundings. Groundings can occur in two basic modes, i.e. as groundings of a manoeuvrable ship and as groundings of a non-manoeuvrable ship, i.e. a ship that has lost propulsion or steering or even both.

- Escort towing mainly prevents groundings of ships that suddenly become non-manoeuvrable. According to an analysis of the Baltic Sea north of the 59° parallel, 15 % of all groundings with a known cause during 1990-2008 were caused by technical faults (Ylitalo et al., 2010). Although technical faults can also relate to other events than loss of power or steering, the latter two events are generally the most important types of technical failure.

- According to the same analysis, 16 % of all groundings occurred because the crew did not appraise the manoeuvring characteristics, current, wind etc. correctly. In such cases, escort towing would equally make a difference.

- Finally, 21 % of all groundings in the analysis occurred due to external factors. Here, wind, waves and currents are assumed to be the main contributor. Escort towing can make a difference also in this case.

Based on the above considerations it can be said that escort towing will affect roughly 50 % of all possible groundings. When considering that escort towing is already in force to some degree in the area analysed by (Ylitalo et al., 2010), the percentage might even be higher. The reason is that escort towing has possibly prevented some groundings, which therefore do not appear in the statistics.

If it is very conservatively estimated that escort towing can prevent 50 % of the groundings, where escort towing can principally have an effect (also 50 %, see above). This leads to a risk reduction by 25 % corresponding to a risk-reduction factor of 0.75.

3.9.10 Icebreaker convoys

Icebreaker convoys involve a number of ships sailing after each other at a close distance. This involves a heightened risk for collisions between the ships of one convoy.

Fraction of affected ships

Icebreaker usage is very common in most Baltic Sea countries stretching north of the 59° parallel (Estonia, Finland, Russia and Sweden). However, actual ice-breaker convoys consisting of 10-20 ships are only common for ships bound to and from Russian ports in the Gulf of Finland (GoF). In practice, this means that such convoys can mainly be expected in the Eastern GoF (Russian EEZ) and on the main sailing route running (EEZ) in the Western GoF.

It is difficult to estimate the number of affected ships, since no statistics are available. It is assumed that all vessels bound to and from Russian ports that do not have ice-breaking capabilities of their own are making use of icebreaker service. Some of them are sailing as single ships behind an icebreaker, while others are sailing in larger convoys. It is estimated that 75 % of all ship movements in the Eastern GoF occur within larger convoys under ice conditions. As far as the main sailing route in the middle of the Western GoF is concerned, the number is estimated to 25 %.

Effect

Figure 3-9 indicates the number of ship-ship collisions related to icebreaker convoy travel. However, since the fraction of ships making use of icebreaker convoys is unknown, it is virtually impossible to derive the probability of a collision with other ships within the convoy statistically.

In the absence of any better information or research results whatsoever, it is estimated that the risk of route collisions between ships sailing in the same direction is doubled when sailing in an icebreaker convoy, corresponding to a risk factor of 2. Note that this type of accident tends to have very little consequences when the involved ships are sailing precisely after each other on precisely the same course. Therefore, the risk increase due to icebreaker convoys will hardly be significant, regardless of the risk factor chosen.

3.10 Risk-increasing properties of shadow fleet vessels

3.10.1 Lower maintenance standards

Approach

The assessment of risk-increasing properties of shadow fleet vessels is based on available inspection data (Equasis, 2026) and focuses on vessel condition as reflected by recorded deficiencies. The shadow fleet is defined as the ships that were on the EU sanction list at the end of 2025.

1. Inspection results from port state control are used as an indicator of vessel condition and safety performance. A higher number of deficiencies is assumed to reflect an increased likelihood of shipping accidents.

2. The analysis compares inspection deficiencies identified for shadow fleet vessels with the general vessel population in the Baltic Sea in order to evaluate whether systematic differences in vessel condition can be observed.

3. To account for the influence of vessel size, the ships are divided into two groups:

   - G1: 25,000–100,000 DWT
   - G2: ⩾100,000 DWT

4. The years 2024 and 2025 are chosen as reference years, since many vessels were not yet classified as shadow fleet ships in 2023, and earlier years therefore do not provide a consistent basis for comparison.

5. In each vessel size group and for each year, a sample of 25 shadow fleet vessels and 25 normal vessels sailing in the Baltic Sea are randomly selected for the analysis.

Results

Figure 3-16 provides an overview of the number of deficiencies identified during inspections in 2024 and 2025 for shadow fleet and normal vessels.

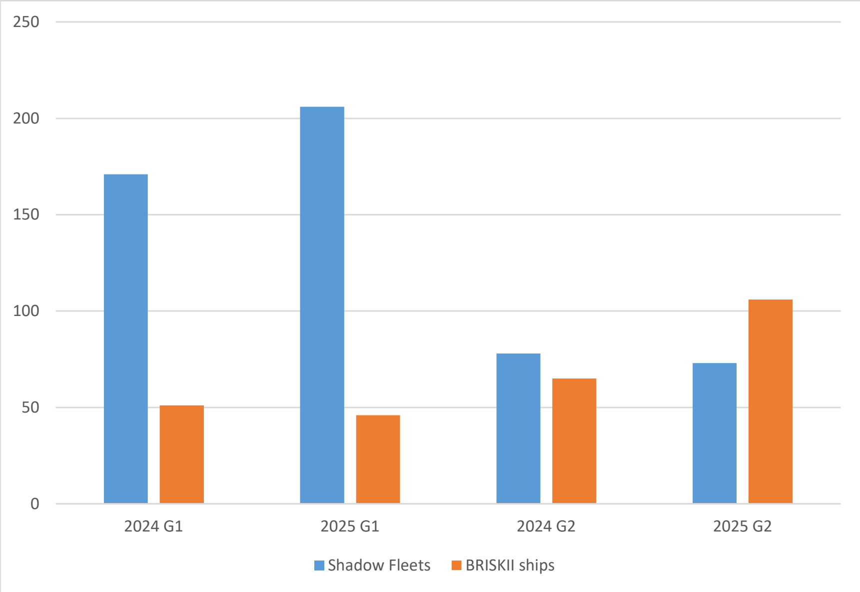


Figure 3-16 *Total number of deficiencies identified during inspections in 2024 and 2025 for shadow fleet and normal vessels ("BRISK II ships") by vessel size group*

The results show a clear pattern for the smaller vessels (G1). In both 2024 and 2025, shadow fleet vessels in this size group exhibit a substantially higher number of deficiencies than BRISK II ships, with the number of deficiencies being up to almost a factor of five higher for shadow fleet vessels. This indicates that smaller shadow fleet vessels tend to be in a comparatively poorer condition. For the larger vessels (G2), no consistent pattern is observed. This may be partly due to the limited sample size, which makes it difficult to identify stable trends for this vessel group. Based on these findings, it is therefore considered appropriate to apply an additional risk factor for shadow fleet vessels in the G1 size group in the risk assessment.

Based on these findings, an additional risk factor reflecting increased accident frequency is therefore should be applied for shadow fleet vessels in the G1 size group in the subsequent risk assessment. The observed increase in deficiencies corresponds on average to a factor of approximately 4 relative to normal vessels.

Some accidents are mainly caused by human error, other are mainly caused by technical failures. Lower maintenance standards can be assumed to affect the probability of the latter type, i.e. accidents caused by technical failure. On the other hand, it can be expected that a ship with a non-compliant maintenance regime also will be non-compliant on crew-related parameters such as watch-keeping discipline, professional capabilities etc. These crew-related factors are, however, unlikely to correspond to a factor of 4.

Thus, it is decided to apply a risk factor of 2 is applied to represent the increased accident frequency of shadow fleet vessels in class G1 (25,000-100,000 DWT). No factor is applied for vessels in class G2 (100,000 DWT and above).

3.10.2 Lower pilotage fraction

As part of the analysis of pilotage usage in Appendix C, it has been investigated whether the fraction of ships using pilots differs between shadow-fleet vessels and normal vessels. This analysis has been carried out for areas with recommended (i.e. not mandatory) pilotage based on data from the Danish waters.

Depending on the ship type, ship size, sea area and sailing direction, it is observed that shadow-fleet vessels are typically 25 % less likely to use a pilot under given circumstances.

In the model, this is implemented in the following way: If a shadow-fleet vessels sails in pilotage area 1, 2, 3, 4, 5, 6, 7 or 8, then the likelihood of using a pilot (pilotage percentage) from Appendix C (Table C-1 to C-6) is reduced by a factor of 0.75.

4 Operational spills from ships

4.1 Introduction

Operational oil spills from ships are the most frequent spill source. They can be the consequence of deliberate action (cleansing of tanks) as well as of accidental action (human or technical failure of equipment without damage to the ship hull). However, most spills are very small and often consist of highly volatile oil products, making it essentially impossible to respond effectively. Nevertheless, these spills contribute to the overall environmental impacts and are therefore included in the model.

The contribution of operational oil spill is modelled based on statistical experience with such spills.

4.2 Historical operational spills

4.2.1 Data sources

HELCOM maintains a database on operational spill (termed *illegal* spills). It contains all spill observations that are obtained by aerial and satellite surveillance by the Helsinki Convention's contracting parties. As opposed to some national databases, it does not contain spill observations accomplished by other means (e.g. non-systematic observations by passing vessels, persons on the coast etc.).

4.2.2 Analysis of historical events

HELCOM's database contains data on spills of mineral oil spills observed during aerial surveillance flights by HELCOM Contracting Parties during 1998-2023. Figure 4-1 illustrates the development in the number of reported accidents during the past 26 years. The overall trend shows a clear decrease from the late 1990s to the mid-2000s, with spill detections declining steadily between 2000 and 2005. This period is followed by a longer phase characterised by comparatively stable accident frequencies at a lower level. Minor year-to-year fluctuations are observed after 2010, including a temporary increase around 2014–2015, but no clear long-term upward trend can be identified. The relatively high numbers observed in the late 1990s and early 2000s might be the consequence of intensified surveillance activity during that period.

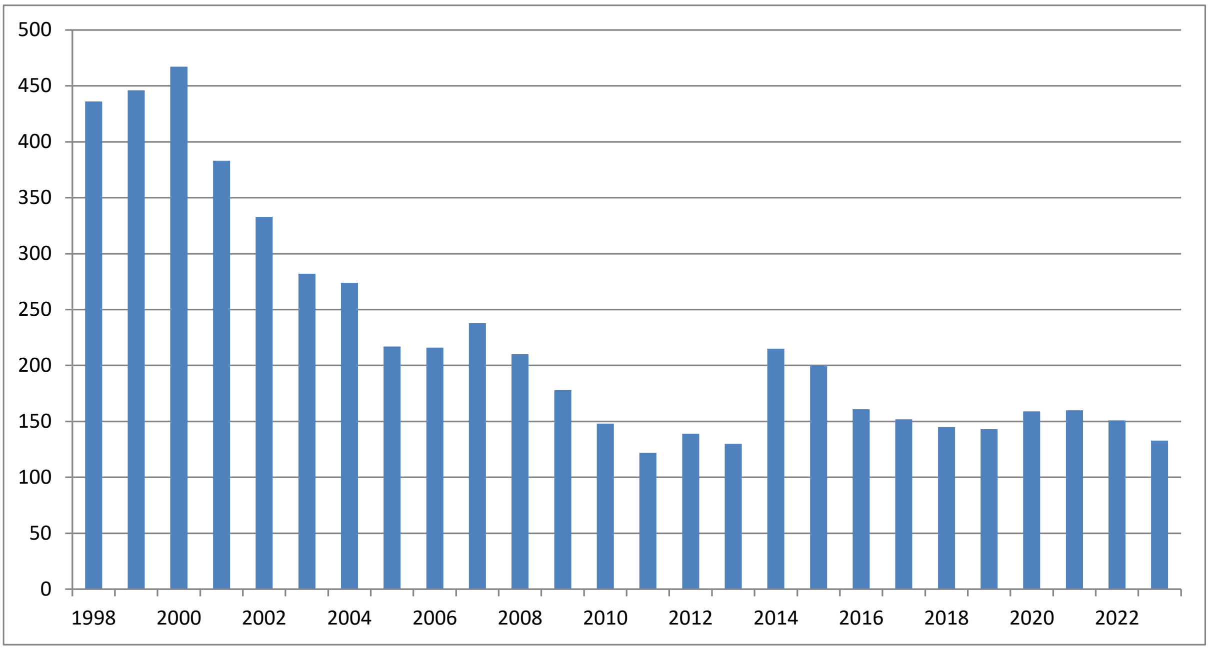


Figure 4-1 Number of operational spills (HELCOM database)

For BRISK II, the subsequent analyses focus on the period 2015–2024, as this period represents the defined scope of the project (BRISK II, Method note, 2025).

Table 4-1 provides an overview over operational spills of different sizes during 2015-2024.

Table 4-1 Observations of operational oil spills during aerial and satellite surveillance in the HELCOM, yearly average 2015-2024 (sorted by EEZ)

Size	DE	DK	EE	FI	LT	LV	PL	RU	SE	Total
< 1 m^3	4.1	6.2	4.3	7.2	0	0	6.3	-	15.4	87.2
1-15 m^3	0.2	0.4	0.1	0.2	0	0	0.2	-	0.3	2.8
15-300 m^3	0	0	0	0.1	0	0	0	-	0	0.2
> 300 m^3	0	0	0	0	0	0	0	-	0	0
Unknown	6.7	16.1	7.7	7.3	0.1	0.1	3.9	-	52.7	190
Total	*22*	*45.4*	*24.2*	*29.6*	*0.2*	*0.2*	*20.8*	-	*136.8*	*280.2*
Total per million sailed miles	*4.8*	*3.3*	*5.4*	*6.7*	*0.5*	*0.1*	*9.2*	-	*9.2*	*5.8*

Figure 4-2illustrates the number of operational oil spills per sailed nautical mile observed in each of the 9 cargo areas.

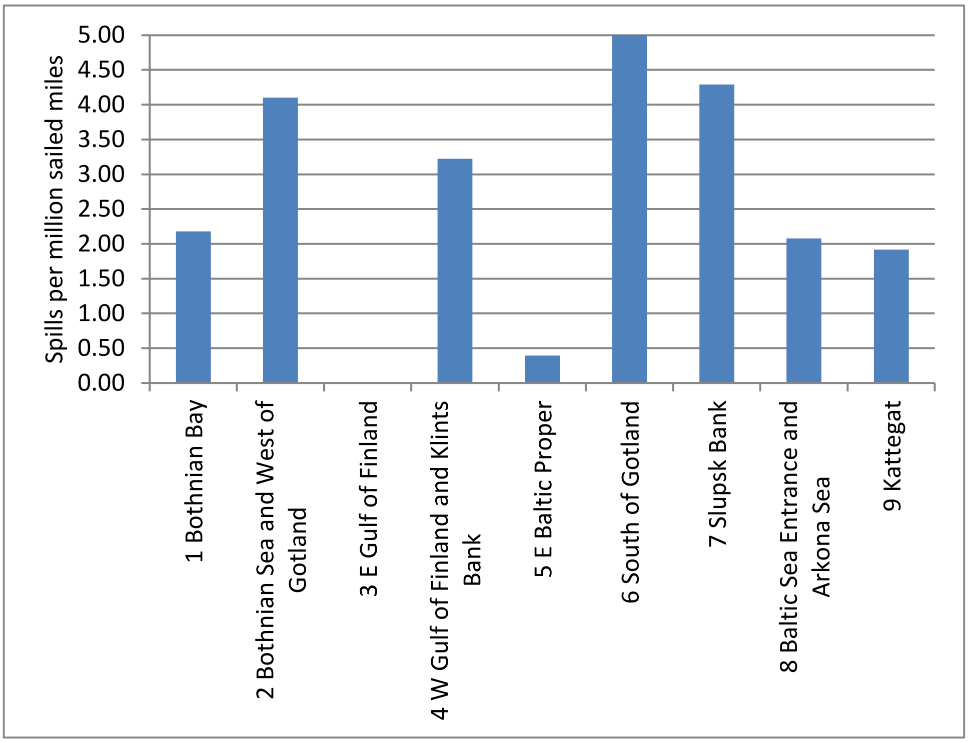


Figure 4-2 *Observations of operational oil spills during aerial and satellite surveillance in the HELCOM, per sailed nautical mile, 2015-2024 (sorted by traffic area)*

4.3 Distribution of spill sizes and oil types

Spill sizes and size distribution

Oil spills are divided into five size classes: <1 m^3, 1-15 m^3, 15-300 m^3, >300 m^3 and unknown size.

The observed spill sizes are somewhat comparable in different HELCOM member countries. Therefore, a universal size distribution is used, as indicated in Table 4-2. This has also the advantage of permitting a realistic estimate for those countries, where the number of observations is small. In addition, it is assumed that events with unknown spill size (67.8 % of all events) have the same size distribution as events with known spill size. This assumption is presumably conservative, since it is unlikely that the size of a large spill is not assessed by the national responsible authority. There has not been any illegal discharges of 300 m^3 or above.

Table 4-2 *Probability of the respective spill sizes in the HELCOM area*

Spill size	<1 m^3	1-15 m^3	15-300 m^3
Probability	96.7 %	3.1 %	0.2 %

Oil types and type distribution

The HELCOM database does not specify the oil type for operational spills. Therefore, earlier experience with the national Danish database is used (Oil spill DK, 2007). There, mineral oil was divided into two types: A light, highly volatile type represented by diesel and a heavy, persistent type represented by IFO

380. Diesel dominated with 88.4 % of all observations, whereas IFO 380 and similar heavy fuels contributed only 11.6 %. Since the share of large ships has increased during the past two decades, it is decided to apply a distribution of 15 vs. 85 % for BRISK II. It should be noted that the released substance is waste oil, not pure fuel.

Table 4-3 Probability of encountering a specific representative substance in case of an operational spill (Oil spill DK, 2007)

Representative substance	IFO 380	Diesel
Probability	15 %	85 %

4.4 Discussion of the overall occurrence of operational spills

Basic estimate

Figure 4-2 provides a general estimate of the expected number of illegal oil spills in the respective traffic areas. Yet, some additional considerations need to be made in order to check whether these numbers need to be corrected.

While it can be said that the majority of all accidents at sea are covered by the accident database, this cannot necessarily be said about the database on illegal and inadvertent oil spills. The reason is a combination of the following:

- The HELCOM database on illegal spills only records events that have been detected due to systematic surveillance with specialised aircraft and satellites. Events reported by other observers are not included.
- Many oil types are volatile and disappear from the sea surface within a few hours. The majority of all illegal and inadvertent oil spills involves volatile oil (compare Table 4-3).
- Aerial and satellite surveillance is not continuous, i.e. there are long time intervals between two surveillance operations. Oil can disappear from the surface in the meantime.
- It is in the nature of operational spills that polluters do not notify the authorities themselves (as opposed to accidents at sea).

Correction for undetected spills

In theory, it could be expected that all spills over a certain minimum size would be detected at some time, as long as they remain floating on the sea surface or reach the coast. In reality, spilt substances are subject to evaporation, dilution, dispersion and sinking.

The fraction of spills that go unnoticed depends on the speed of those processes and on the interval in which the affected area is covered by systematic surveillance.

Based on the principles introduced in D3.3 Risk of oil and HNS impact (BRISK II, Impact, 2026), it can be stated that volatile oil types such as diesel disappear comparatively fast. After 10 to 12 hours, 90 % of the spilt oil volume is typically gone, depending on the temperature. In the case of non-volatile, heavier compounds, where different decay mechanisms are acting, it will typically take one to five days, until 90 % of the oil has disappeared from the sea surface.

Considering the frequency of aerial surveillance flights and satellite coverage, it appears likely that the prevailing number non-volatile oil spills are detected. This is probably not the case with volatile oil spills. However, it can be argued that spills that go unnoticed cannot be contained by emergency response measures either. In addition, it can be expected that the average size of unnoticed spills is even smaller than that of detected and confirmed spills. 96.7 % of all confirmed operational spills where the actual spill size is known are smaller than 1 m^3 (see Table 4-2). Therefore, no correction for undetected spills is introduced in the model.-2

Spill of other hazardous substances than oil are only observed rarely.

Conclusion

It is concluded that the most rational approach is to apply the values in Figure 4-2 for calculating the expected number of illegal spills per year and traffic area. However, it is decided to make two area-specific modifications:

- Area 3 Eastern Gulf on Finland: Due to lack of data, the same rate as for Western Gulf on Finland is applied
- Area 5 Eastern Baltic Proper: Due to unrealistically low numbers, the average of the adjacent areas 2, 4, 6 and 7 is applied

5 Offshore oil transfer

5.1 STS operations

When cargo is transferred from one ship to another at the open sea, this action is referred to as ship-to-ship transfer (STS). STS operations normally involve the transfer of oil cargoes by hose. Transfer of other relevant substances, e.g. chemicals, is theoretically possible. However, no instance of such an event is known within the Baltic Sea.

General situation

Denmark and Sweden are the only countries where such operations occurred during 2024. Typically, these transfers occur north of the Great Belt, which is too shallow for being used by some crude oil tankers when fully loaded. These tankers pass the Great Belt partly loaded and receive additional cargo from a feeder ship after the passage.

Identification of locations and number of operations

The first step consists in identifying the main STS transfer location, which tend to be concentrated in geographically confined areas.

In the case of Denmark, there are two main locations, where STS operations take place. In Denmark, 21 STS operations were carried out in 2024. The largest part (20 occurrences) was carried out off Frederikshavn, one in Kalundborg. As direct information on transferred cargo volumes is not available for the individual STS operations, the transferred volumes have been estimated. For the present assessment, the transferred volume per operation is assumed to correspond to 75% of the smaller deadweight tonnage (DWT) of the two involved vessels. Based on this assumption, the total transferred volume during the observation period is estimated at approximately 0.5 million tonnes of oil, of which about 96.5% was transferred in the offshore area off Frederikshavn. Compared to the reference situation in 2009, the extent of STS activity in Denmark has decreased substantially. While approximately 9.5 million tonnes of oil were transferred in 2009, the total transferred volume in 2024 is estimated at approximately 0.5 million tonnes. This corresponds to a reduction by a factor of about 20.

In the case of Sweden, In 2024, a total of 116 vessels indicated STS as their intention in the fairway declaration to the Swedish Maritime Administration. The majority of these were carried out in the Göteborg area, accounting for 63 occurrences. Additional STS-related occurrences were observed at Nord Ven (Helsingborg) with 12 occurrences, Luleå with 11 occurrences, Karlshamn with 7 occurrences, and Visby with 6 occurrences. Smaller numbers of occurrences were recorded at Malmö (3), Rivöfjorden near Göteborg (3), Simrishamn (2), Stockholm (2), Trelleborg (2), and at the offshore Trubaduren B and C locations (2 occurrences each). Oxelösund accounted for one STS-related occurrence during the period. As the available Swedish data do not include information on the involved vessels or transferred cargo volumes, it is not possible to estimate transferred tonnage in a manner comparable to the Danish assessment.

Hazard identification

The following major hazards can be identified:

- Operational spill due to hose rupture or overfilling

- Spill due to collision with the feeder ship
- Spill due to collision with a passing vessel

Leakage from the ship hull, e.g. due to fire or other causes is covered by Chapter 3.

Risk of spill

The risk of oil spills due to STS operations is analysed in detail in Appendix D, where each location and hazard is investigated and discussed separately. The analysis of the ship impact frequency is based on Fujii's model (see Section 3.2.1) in combination with other considerations and previously existing risk analyses.

5.2 Bunkering at sea

General situation

Bunkering at sea was only observed in Danish waters during 2024. No such operations were identified in the other Baltic Sea countries.

Identification of locations and number of operations

The first step consists in identifying the main bunkering-at-sea locations. Table 5-1 provides an overview of the geographical distribution of bunkering-at-sea cases recorded in Danish waters during 2024. The results show a very strong concentration of activities in Ålbæk Bugt, which accounts for the majority of all identified cases. Only a limited number of bunkering-at-sea cases were recorded in other Danish sea areas, including Åbenrå Fjord, Kalundborg Fjord, Århus Bugt and the waters around Læsø. These areas together represent only a marginal share of the total activity.

Table 5-1 Distribution of bunkering-at-sea cases in Danish waters in 2024

Area	Number of bunkering-at-sea cases
Ålbæk Bugt	2,827
Other	22
Åbenrå Fjord	5
Læsø	4
Kalundborg Fjord	4
Århus Bugt	3
Total	*2,865*

Hazard identification

The following major hazards can be identified:

- Operational spill due to hose rupture or overfilling

- Spill due to collision with the feeder ship
- Spill due to collision with a passing vessels

Leakage from the ship hull, e.g. due to fire or other causes is covered by Chapter 3.

Risk of spill

The risk of oil spills due to bunkering at sea is analysed in detail in 8Appendix D, where each location and hazard is investigated and discussed separately. The analysis of the ship impact frequency is based on Fujii's model (see Section 3.2.1) in combination with other considerations and previously existing risk analyses.

As with STS operations, the bunkering-specific risk is significantly smaller than the risk due to ship-ship collisions and groundings in the respective areas. However, bunkering is a serious risk contributor in the Ålbæk Bay, i.e. the area northeast of Frederikshavn.

5.3 Loading buoys

The only offshore loading buoy currently operated in the Baltic Sea is located off the Lithuanian coast close to Butinge.

Hazard identification

The following major hazards can be identified:

- Operational spill due to hose rupture or overfilling
- Spill due to ship impact of a passing vessel against vessels moored to the loading buoy
- Leakage from the ship hull, e.g. due to fire or other causes is covered by Chapter 3.

Risk of spill

The risk of oil spills related to the Butinge loading buoy is analysed in detail in Appendix D. The analysis of the ship impact frequency is based on Fujii's model (see Section 3.2.1) in combination with other considerations and previously existing risk analyses.

6 Spill from offshore installations

A number of offshore oil installations are exposed to potential ship collisions:

- The Russian D-6 platform
- The Polish PG1 and Baltic Beta platforms
- The Lithuanian offshore oil loading buoy at Butinge

If a ship hits an offshore oil installation, oil can leak both from the installation and from the involved ship. It is estimated the spill risk related to the platform clearly dominates over the spill risk related to the involved ship. Therefore, the spill risk from the ship hull is not modelled (compare Section 3.7).

Note that spills related to offshore oil terminals are dealt with separately in Section 5.3.

6.1 Spill due to ship impact

The risk of oil spills due to ship collisions against offshore installations is analysed in detail in Appendix D. The analysis of the ship impact frequency is based on Fujii's model (see Section 3.2.1) in combination with other considerations and previously existing risk analyses.

Dedicated ships

Collisions of dedicated ships with offshore installations occur comparatively frequently. However, most events are low-energy collisions while the ship is slowly closing in on the platform or keeping a fixed position next to the platform. The frequency of high-energy collisions potentially leading to spill from the ship or the platform is reasonably low. Therefore, the resulting risk is comparable to that of other types of accidents in the area (ship-ship collisions etc.). See Appendix D for details.

Passing ships

In the case of the Polish platforms, the frequency of collisions of passing ships is very low. Therefore, this type of risk is insignificant compared to the risk originating from dedicated ships or from other types of accidents in the area (ship-ship collisions etc.). See Appendix D for details.

As far as the Russian D-6 platform is concerned, an aggregated risk number was received from the Russian project partner during BRISK I (BRISK-RU project). It contains both spills due to ship impact and other spill causes. See Appendix D for details.

6.2 Spill due to other causes

Operational spills

Spills can occur due to other causes than ship impact. For the platforms in the Baltic Sea, such spills occur mainly due to operational causes.

As far as the Polish platforms are concerned, operational spills other than blow-outs are estimated to be smaller than 15 tonnes per event. Considering that the frequency of such spills is very low, this means that operational spills do not contribute significantly to the overall risk of spill in the area (which is dominated by ship-ship collisions). A possible blow-out is not modelled. Details can be found in Appendix D.

Spills due to offshore exploration and drilling

There are no indications on ongoing or planned exploration and drilling activities. Therefore, this risk is not modelled.

Fire and explosion

Fire and explosions on the platform are another possible source of spill risk. However, this contribution is considered to be insignificant compared to the above-mentioned potential spill causes.

As far as the Russian D-6 platform is concerned, an aggregated risk number was received from the Russian project partner during BRISK I (BRISK-RU project). As already mentioned in Section 6.1, it contains both spills due to ship impact and other spill causes.

7 Abbreviations

AIS	Automatic Identification System
BNWAS	Bridge Navigational Watch Alarm System
ECDIS	Electronic Chart Display and Information System
EEZ	Exclusive economic zone
HNS	Hazardous and noxious substances
IMO	International Maritime Organisation
LR	Lloyd’s Register
Ro-Ro	Roll-on roll-off
Ro-Pax	Roll-on roll-of combined with passenger transport
RRM	Risk-reducing measure
STS	Ship-to-ship transfer
TSS	Traffic separation scheme
VTS	Vessel traffic service

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Appendix A Collision frequency model

A.1 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 A-1.

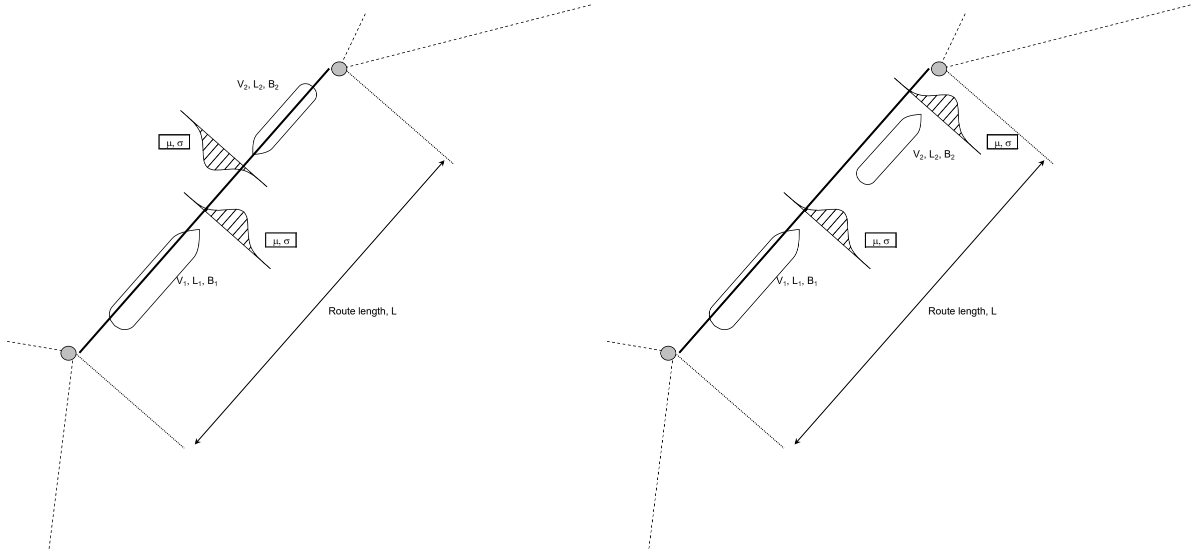

Figure A-1 Head-on and overtaking collisions

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 the traffic analysis (BRISK II, Traffic analysis, 2025) provide this kind of information for each route leg.

Calculation

For the 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 these properties are directly relevant for the collision probability (breadth, speed), whereas others are relevant for the consequences of the collision (ship type and deadweight tonnage).

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, 1984). In the context of the Great Belt Fixed Link project, 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 (Oil spill DK, 2007). For the BRISK I project, calibration against accidents numbers during the years 2004-2008 resulted in $P_c = 4.0 \times 10^{-4}$. For the specific case of the Drogden channel in the Sound off Copenhagen, a revised factor of $P_c = 1.3 \times 10^{-4}$ was applied based on an earlier location-specific analysis (Drogden, 2001). Using a value of 4.0×10^{-4} would have led 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 project area justifies this separate modelling decision.

Figure A-2 and Figure A-3, respectively, show the number of ship-ship collisions in the project area in the years up to BRISK I and up to BRISK II. Numbers have not significantly risen or fallen between these periods. However, traffic has changed and so has the extent of risk-reducing measures (more traffic separation systems, more usage of ECDIS etc.).

Thus, as a working assumption it is assumed that the values from BRISK I are still valid, meaning

$P_c = 4.0 \times 10^{-4}$ ... all route except for Drogden
$P_c = 1.3 \times 10^{-4}$ ... Drogden

These parameters will be verified against the risk model results as part of the next BRISK II deliverable, i.e. report D2.6 Probability of oil and HNS release (BRISK II, Prob. of release, 2026).

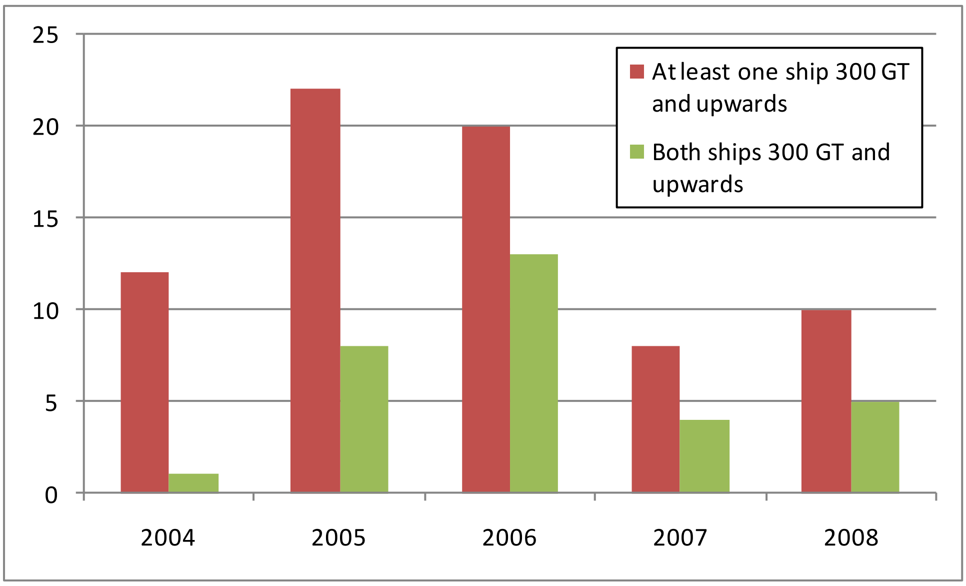

Figure A-2 Number of collisions in the BRISK area per year, 2004-2008 (BRISK I, Spill, 2012)

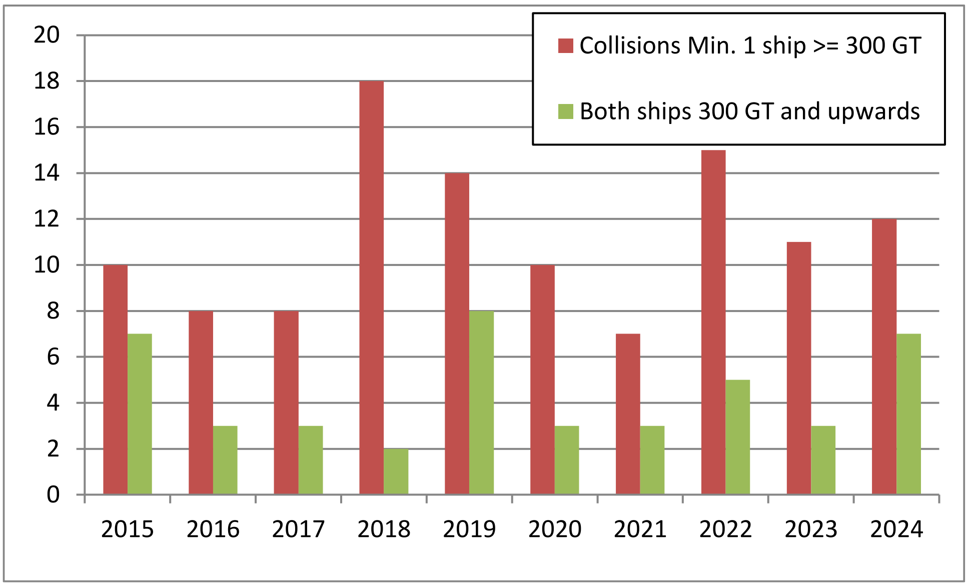

Figure A-3 Number of collisions in the BRISK area per year, 2015-2024

Risk reduction factor

Different factors can have a reducing factor upon collision risk. These factors are described in section 3.9 of this report.

A.2 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, i.e. the probability that the traces of both ships intersect
- the traffic intensity in each of the two directions
- breadth, 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.

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

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. This assumption is also applied for BRISK II.

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 A-4:

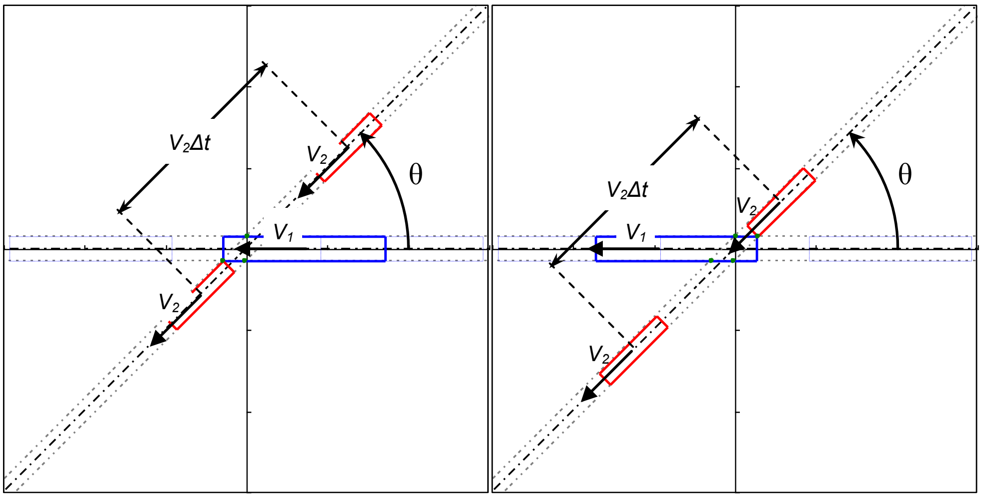

Figure A-4 Geometrical determination of the critical time interval/route length for a node collision

The critical time interval is determined as

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

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

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

Causation probability

This quantity is chosen as

$P_c = 4.0 \times 10^{-4}$ … entire Baltic Sea

for the same reasons as for route collisions above. Again, this a working assumption that will be checked and if needed adjusted as part of deliverable D2.6 Probability of oil and HNS release (BRISK II, Prob. of release, 2026). Note, that no separate value is applied for the Drogden channel. The reason is that the channel is only atypical with respect to the risk of route collisions.

Risk reduction factor

Different factors can have a reducing factor upon collision risk. These factors are described in section 3.9 of this report.

Appendix B Grounding frequency model

B.1 Introduction

This appendix describes the establishment of the grounding frequency model and is part of the grounding risk analysis described in Section 3.4.

The approach for calculating the grounding frequency is simple and based upon the available data and statistics.

- In deliverable D2.4 (BRISK II, Cargo analysis, 2025), the Baltic Sea has been divided into several traffic areas. For each of these areas, a number of representative grounding points (grounding locations) is identified (B.2)

- For each traffic area, the grounding frequency is calculated, based on historical accident data and divided with the number of nautical miles sailed per year. The result is a raw grounding frequency per sailed nautical mile. Each traffic area has a different frequency (Section B.3).

- The grounding frequency is corrected for the effect of risk-reducing measures (RRMs) such that a "clean" basic grounding frequency is obtained (Section B.4).

- The grounding frequency in each traffic area is distributed among the representative points. This is done by means of a factor describing the relative weight of each grounding point (Section B.5).

Section B.6 provides an overview of how the grounding frequency is finally compiled in the analysis model.

The effect of sea ice during winter is taken into account by the traffic model, which is one of the main input parameters of the grounding model. Amongst other effects, sea ice influences the traffic intensity on the respective routes (BRISK II, Traffic analysis, 2025). Grounding frequencies are calculated separately for the ice season and the ice-free season.

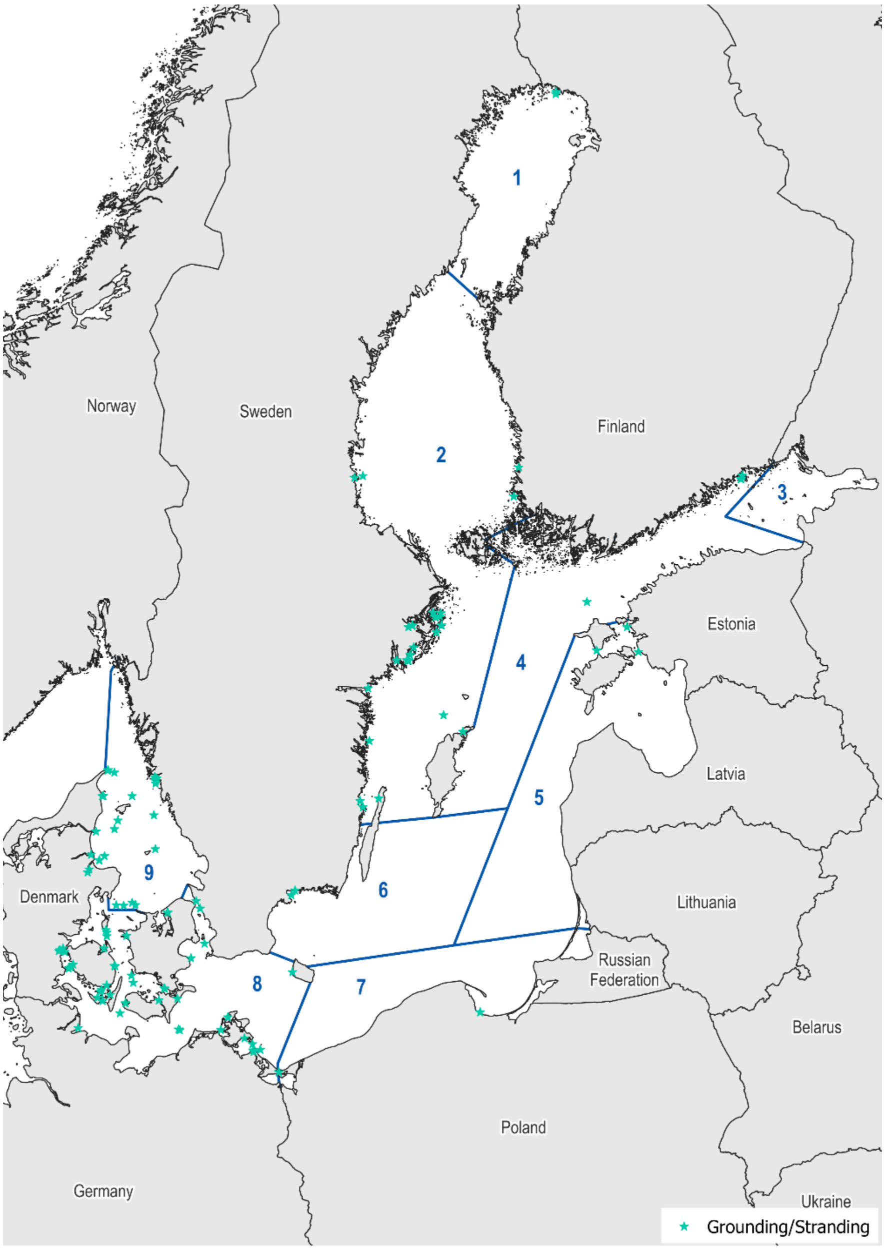

Figure B-1 *Grounding accidents 2015-2024 and traffic areas*

B.2 Establishment of the representative points

Approach

In BRISK I (BRISK I, Traffic, 2012), the Baltic Sea was divided into 16 traffic areas, within which representative grounding points were established based on historical grounding statistics, bathymetry, and traffic patterns. Three criteria are considered when identifying a representative grounding point:

- Locations, at which groundings have been observed in the past. All statistically recorded events are of interest, regardless of whether they involved tank ships or ship types without hazardous general cargo. Only groundings for which coordinates are given are referred to in the text (called localised groundings).

- Locations, at which groundings can be expected, because of the relative position of navigation routes and shallows.

- Locations, at which groundings are not necessarily likely, but would have significant consequences due to the high vulnerability of the local ecosystem regarding oil and chemical spills.

In this note, no new grounding locations are introduced. Instead, the existing representative grounding points from BRISK I are retained and mapped onto the updated cargo-area structure applied in BRISK II (BRISK II, Cargo analysis, 2025). This is because the grounding accidents recorded during the period 2015–2024 are all located within the representative grounding points identified in BRISK I (BRISK I, Spill, 2012Figure B). Consequently, the existing set of grounding locations is considered sufficient to describe the spatial distribution of grounding risk for the purpose of the BRISK II analysis.

General remarks

In this note, ships smaller than 1000 GT are referred to as small, ships above 10,000 GT as big and everything in between as medium.

B.2.1 Cargo area 1 (Bothnian Bay)

Establishment of representative points

The following points are deemed representative:

1 Örngrundet (65.27° N, 22.02° E) is chosen to represent possible groundings on the approaches to Luleå and Piteå.

2 The little skerry of Etukari (65.67° N, 24.20° E) has been the location of one grounding as is deemed to be sufficiently representative for the entire approach to Haparanda/Tornio.

3 The Kutumatala shallow (65.10° N, 25.10° E) is chosen as a representative point for groundings on the approach to Oulu.

4 The Maanahkiainen shallow (64.63° N, 24.22° E) is chosen as a representative point for grounding on the approach to Raahe. This shallow has been the location of a grounding during the observation peroid.

5 The Mässkär skerry (63.73° N, 22.58° E) is deemed to be represenative for groundings on the approach to Pietarsaari.

6 The Skotrevet shallow (64.60° N, 21.53° E) is deemed to be representative for groundings on the approach to Skellefteå.

7 The narrowest point of Norra Kvarken at Nordvalensgrund shallow (63.54° N, 20.77° E) is chosen as representative point for the Norra Kvarken straight.

B.2.2 Cargo area 2 (Bothnian Sea and West of Gotland)

Establishment of representative points

The following points are deemed representative:

1 Fjärdgrund shallow (63.67° N, 20.35° E) is chosen in order to represent the grounding risk on the approach to Umeå. One ship grounded exactly here, two more ships grounded nearby.

2 Sjögrund shallow (62.80° N, 20.54° E) is chosen because of an earlier grounding at this location and in order to represent the nearby approach to Vaasa.

3 The approach to Kristiinankaupunki (62.25° N, 21.37° E)

4 Kupeli shallow (61.64° N, 21.33° E) is chosen in order to represent the approach to Pori. One accident occurred precisely here, two others happened nearby.

5 Leviamatala shallow (61.10° N, 21.35° E) has been the site of two groudings. With a third grounding nearby, it represents the approach to Rauma.

6 Hälsingskär shallow (60.63° N, 20.90° E) is close to the site of one grounding. Besides, it represents the other observed and potential grounding locations north of the Åland islands as well as on the approach to Uusikaupunki.

7 Själstenarna shallow (60.72° N, 17.50° E) represents accidents around the approach to Gävle. One accident has occurred on this site, three more happened nearby.

8 Västeråsen shallow (62.33° N, 17.54° E) represents the approach to Sundsvall, which is one of the busiest ports in the area.

9 Själgrunden shallow (60.28° N, 18.72° E) represents the approach to Hargshamn. One grounding occurred on this site, two more happened nearby.

10 Märbådan shallow (60.03° N, 19.88° E) is chosen to represent groundings along off the southwestern coast of the Åland archipelago. One grounding occurred on this site, two more happened not so far away.

11 The fairway of Norrfjärden (60.11° N, 20.47° E) is chosen to represent groundings between the islands and skerries of the Åland archipelago. One grounding occurred on this site, three more happened nearby.

12 Salvorev shallow (58.02° N, 19.35° E) represents the between Fårö and Gotska Sandön. One accident occurred on this site.

13 Deppö shallow (57.15° N, 18.05° E) represents the area along the southwestern coast of Gotland.One accident occurred on this site.

14 Örskärsbåden shallow (57.47° N, 16.82° E) represents the Swedish coastline around Oskarshamn and the northern part of the sound between the Swedish mainland and Öland. One grounding occurred precisely at this site.

15 Gumbådarne shallows (58.65° N, 17.58° E) represents the approaches to Oxelösund, Södertälje and Norrköping. Three groundings occurred south of the chosen site, another three occurred north of it.

16 The shallows off Ingarö (59.22° N, 18.60° E) represent the Stockholm archipelago. One grounding occurred on this site, two more happened in other parts of the archipelago.

B.2.3 Cargo area 3 (Eastern Gulf of Finland)

The following points are deemed representative:

1 The most narrow passage on the approach to Vysotsk (60.61° N, 28.55° E). Ships heading towards Vyborg and the Saimaa Canal are equally forced to use this passage. Seven groundings have occurred in the area, one precisely at the chosen location.

2 Grekov bank (60.19° N, 28.69° E) represents the approach to Primorsk.

3 Severnaya Moshchnaya Banka shallow (60.13° N, 27.87° E) represents the intensely sailed area north of Moshchnyy and Lesnoy islands.

4 Severnyy Virgin skerry (59.95° N, 26.87°) represents the intensely sailed area next to Högland island.

5 Samoyed bank (59.88° N, 28.22° E) represents the approach to Ust-Luga.

B.2.4 Cargo area 4 (Western Gulf of Finland and Klints Bank)

Establishment of representative points

The following points are deemed representative:

1 The group of small shallows located in Skjaldholmsfjärden (60.23° N, 21.67° E) represents the area between and north of Nauvo and Korppoo. Three groundings occurred in this area.

2 The skerry of Rajakari (60.37° N, 22.09° E) is chosen to represent the approach to Turku and Naantali. One actual grounding occurred nearby, close to the port of Naantali.

3 Prisgrund shallow (59.87° N, 22.43° E) represents the southeastern confines of the Archipelago Sea. One grounding occurred nearby.

4 Stenharun shallow near Utö (59.80° N, 21.32° E) represents the southern confines of the Archipelago Sea. One grounding occurred on the site, another one only two nautic miles away.

5 Hiiumadal shallow (59.08° N, 22.27° E) represents the northern and northwestern coast of Hiiuma island.

6 Södra Skrikgrunden shallow (57.15° N, 18.52° E) represents the east coast of Gotland. One accident occurred on the site, another one 20 nautic miles to the north.

7 Hästgrund shallow (59.91° N, 24.16° E) represents the approach to Inkoo.

8 Harmaja shallow (60.10° N, 24.97° E) represents the approach to Helsinki. Four groundings occurred in the area, one of them precisely at the chosen location.

9 The skerry of Tunnholmen (60.19° N, 25.77° E) represents the approach to Porvoo. Three groundings occurred in the area, one of them precisely at the chosen location.

10 Ruotsinsalmi fairway (60.47° N, 27.01° E) represents the approach to Kotka, being the site to two groundings in the observation period. Besides, the point represents other accident locations to the east and west, such as Loviisa and Ruissaari/Mustamaa.

11 Ruamadal shallow (59.71° N, 26.11° E) represents the approach to Kunda.

12 The shelf to the south of Prangli (59.60° N, 25.00°) represents the area south of Prangli (four observed groundings) and Muuga (one observed accident)

13 Keskmadal shallow (59.59° N, 24.65° E) represents the approach to Tallinn, where four groundings were observed.

14 Krassi shallow (59.36° N, 23.79° E) represents the area around Paldiski. Three groundings occurred in the area, one of them precisely at the chosen location.

15 Tsernovimadal (59.20° N, 23.31° E) represents the area around Dirhami. Two groundings occurred in the area, one of them precisely at the chosen location.

B.2.5 Cargo area 5 (Eastern Baltic Proper)

Establishment of representative points

The following points are deemed representative:

1 Kumarimadal shallow (58.77° N, 23.26° E) represents the waters between Hiiumaa, Saaremaa and the Estonian mainland.

2 Kihnumadal shallow (58.06° N, 23.91° E) represents the approach to Pärnu.

3 Randa shallow (57.82° N, 24.27° E) represents the area near Salacgriva.

4 Mihailova shallow (57.75° N, 21.75° E) represents the Irbe Strait and its surroundings. One accident happened precisely at this location.

5 The shelf area north of Klaipeda (55.90° N, 21.01° E) represents the area next to Klaipeda.

B.2.6 Cargo area 6 (South of Gotland)

Establishment of representative points

The following points are deemed representative:

1 Utgrunden (56.36° N, 16.27° E) represents the fairway between southern Öland and the Swedish mainland.

2 Norra Midsjöbanken (56.21° N, 17.40° E) represents the open sea southeast of Öland. This location is chosen rather than Södra Midsjöbanken (further off the coast, i.e. less environmental sensitivity) and Hoburgs Bank (there is a representative point in traffic area 4 nearby).

3 Davids Banke (55.37° N, 14.66° E) represents the northeastern part of the Bornholmsgat including the shelf area around Christiansø.

4 Laxgrund (56.05° N, 14.80° E) represents the area around Karlshamn (the Hanöbukten). It has been the site of one grounding during the reference period.

B.2.7 Cargo area 7 (Slupsk Bank)

Establishment of representative points

The following points are deemed representative:

1 The shallows next to the entrance to the Vistula Lagoon (54.65° N, 19.86° E).

2 The area between Baltiysk and Komsomolsk (54.64° N, 20.03° E) represents the approach towards Kaliningrad port.

3 The centre of the Polish part of the Vistula Lagoon (54.37° N, 19.54° E) represents the approach towards Elblang.

4 A minor shallow (54.45° N, 18.69° E) on the approach to Gdansk represents the Gdańsk Bay.

5 Slupsk Bank (54.97° N, 16.58° E)

B.2.8 Cargo area 8 (Baltic Sea Entrance and Arkona Sea)

Establishment of representative points

The following points are deemed representative:

1 Svartgrund (55.24° N, 14.25° E) represents the entire Sandhammaren area.

2 Nyker Rev (55.15° N, 14.70° E) represents the west coast of Bornholm.

3 The northeastern tip of Adler Grund (54.82°, N 14.47° E) represents Adler Grund and Rønne Banke.

4 The shallows at the entrance to Greifswalder Bodden (54.24° N, 13.70° E)

5 The 4-meter depth contour at Cape Arkona (54.69° N, 13.43° E)

6 Kriegers Flak (55.05° N, 13.03° E)

7 Gyldenløves Flak (55.12° N, 12.46° E)

8 Falsterborev (55.33° N, 12.62° E)

9 Plantagenet Grund (54.65° N, 12.80° E)

10 The southern end of Gedser Rev (54.48° N, 12.18° E) represents the many accidents with large accidents in this area. Accidents off Gedser and Darss are equally represented by this point.

11 Gammel Tolk shallow (54.86° N, 12.20° E) represents the Grønsuns and the Hjelm Bay.

12 Walküriengrund (54.11° N, 11.04° E) represents the Bay of Lübeck.

13 Øjet shallow (54.62° N, 11.15° E) represents the central part of the Fehmarn Belt.

14 Kolberger Heide (54.45° N, 10.31° E) represents the approach to Kiel and the Kiel Canal.

15 Issehoved (56.05° N, 10.60°) represents the area between Samsø in the south and Mols peninsula in the north as well as the area off Århus port.

16 The eastern end of Svanegrund (55.82° N, 10.45° E) represents the area between Samsø in the east and Jutland in the west.

17 Æbelø NV-Rev (55.65° N, 10.16° E) represents the area north of Funen and the northern central part of the Little Belt.

18 55.50° N, 10.55° E represents the Odense Fjord.

19 Lyø W-Flak shallow (55.05° N, 10.09° E) represents the area between Als and Funen.

20 Bastholm Hage shallow (55.30° N, 9.77° E) represents the southern central part of the Little Belt.

21 Lyngsodde Flak shallow (55.52° N, 9.74° E) represents the narrow central part of the Little Belt. It has a minimum depth of 8 metres.

22 Hatter Rev (55.89° N, 10.83° E)

23 Elefantgrund (55.53° N, 10.92° E)

24 Agersø Flak (55.20° N, 11.12° E)

25 South end of Langeland (54.73° N, 10.83° E). This point represents the accidents in this area and those in the central part of the Langeland Belt. Furthermore, accidents were observed in the Fehmarn Belt traffic area closeby, but have not been used for establishing a representative point there.

26 Smålandsfarvandet is not frequented by big ships, but combines a noticeable amount of small and medium ships with shallow waters and a globally very sensitive environment. Kogrund (54.97° N, 11.65° E) represents this area.

27 Kråsebænken shallow (55.60° N, 12.72° E) represents Drogden and the whole area east and north of Amager.

28 55.89° N, 12.64° E represents the area off Ven as well as the main part of the Sound between Copenhagen and Helsingør/Helsingborg.

29 56.09° N, 12.51° E represents the coast of Sealand north of Helsingør.

30 Juelsgrund shallow (55.45° N, 12.34° E) represents the southwestern part of the Sound, i.e. the part that lies south of Copenhagen.

B.2.9 Cargo area 9 (Kattegat)

The Kattegat traffic area consists of the Kattegat itself as well as the easternmost part of the Skagerrak (the area that is delimited by a line running from the Skaw to the Swedish-Norwegian border). The Limfjord and the Isefjord are not part of the scope.

1 Skagens Rev (57.76° N, 10.71° E)

2 56.88° N, 10.55° E represents the approach towards Hals and the Limjord.

3 Tangen (56.60° N, 10.55° E) represents the entrance of Randers Fjord and Tangen shallow.

4 Naveren shallow (56.40° N, 10.94° E) represents the coastal area around Grenaa.

5 Yderflak (56.07° N, 11.02° E) represents the shallows between Sjællands Odde and Ebeltoft, including Sjællands Rev, Moselgrund, Marthe Flak and Hjelm Banke.

6 Store Middelgrund (56.55° N, 12.07° E)

7 Fladen (57.18° N, 11.74° E)

8 57.66° N 11.71° E represents the Gothenburg archipelago

9 57.92° N, 11.62° E represents the area around Tjörn island.

10 58.26° N, 11.44° E represents the area between Lysekil and Sotenäs.

B.3 Raw grounding frequency

Table B-1 illustrates the grounding frequencies in the different traffic areas, both as occurrences per year and as occurrences per sailed nautical mile.

Table B-1 Groundings per year and per sailed nautical mile

Cargo area	Groundings 2015-2024	Groundings per year	Groundings per sailed nautical mile
1 Bothnian Bay	2	0.2	2.42×10^{-7}
2 Bothnian Sea and West of Gotland	27	2.7	4.58×10^{-7}
3 E Gulf of Finland	0	0	5.69×10^{-8}
4 W Gulf of Finland and Klints Bank	5	0.5	5.69×10^{-8}
5 E Baltic Proper	3	0.3	1.07×10^{-7}
6 South of Gotland	2	0.2	3.06×10^{-8}
7 Slupsk Bank	2	0.2	8.25×10^{-8}
8 Baltic Sea Entrance and Arkona Sea	48	4.8	3.42×10^{-7}
9 Kattegat	28	2.8	5.01×10^{-7}
Total	117	11.7	2.41×10^{-7}

The Gulf of Bothnia and the Gulf of Finland are affected by sea ice practically every winter. Due to the low absolute number of grounding events during ice season, it is not possible to determine the effect of ice upon grounding rates for each traffic area separately in a reasonable way. Instead, groundings from all traffic areas that are regularly affected by sea ice are treated as one population in order to determine the effect of sea ice.

Table B-2 compares the difference in grounding frequencies per sailed mile between ice season and ice-free season. As compared to the whole-year average, grounding rates are elevated by 30 % during ice season and reduced by 10 % during ice-free season. These factors are included in the model for the affected traffic areas.

Note however, that the definition of "ice" and "no ice" is attached with some uncertainty. The local ice situation has not been verified for every single event.

Table B-2 Seasonality of groundings in the Gulf of Bothnia and the Gulf of Finland

Season	Groundings 2015-2024	Groundings per year	Groundings per nautical mile
Ice season	5	0.5	4.28×10^{-8}
Ice-free season	11	1.1	2.99×10^{-8}
Whole year	16	1.6	3.30×10^{-8}

B.4 Basic grounding frequency

The BRISK model operates with a number of risk-reducing measures (RRMs) that reduce the basic accident frequencies. The raw grounding frequency described in Section B.3 are based on actual statistics and do therefore already include these effects. To not to count the same RRMs twice, it is necessary to determine the "basic" grounding frequency, i.e. the grounding frequency that would be observed, if no RRMs were in place. The basic grounding frequency is an input to the BRISK grounding model.

The approach used to determine the basic grounding frequency follows the methodology applied in BRISK I (BRISK I, Spill, 2012). The procedure consists of the following steps:

- In a first step, use the raw grounding frequency instead of the basic grounding frequency as calculation input and make a test run.
- Compare the calculation results with the statistical results. The calculation results F_{test} will show a lower frequency than the statistics F_{stat}, which is due to double-counting of the RRM effect. The difference can be expressed as a correction factor $x_{corr} = F_{stat} / F_{test}$.
- Calculate the basic grounding frequency as $F_{basic} = F_{stat} \times x_{corr}$.

The numerical application of this method requires calculated grounding frequencies. As these results are not established within the scope of the present deliverable, the determination of basic grounding frequencies cannot be performed in this report and will therefore be addressed in D2.6 (BRISK II, Prob. of release, 2026).

For illustration purposes only, results from BRISK I are presented as an example of how the method is applied in practice. The results are displayed by Table B.

Table B-3 *Basic grounding frequency per sailed nautical mile (BRISK I)*

Traffic area	Raw grounding frequency per mile (incl. RRMs)	Implied risk-reduction factor	Basic grounding frequency per mile (without RRMs)
1 Bothnian Bay	1.7×10^{-6}	0.7	2.6×10^{-6}
2 Bothnian Sea	1.1×10^{-6}	0.8	3.7×10^{-6}
3 West of Gotland	7.4×10^{-7}	0.7	1.1×10^{-6}
4 Klints Bank	2.4×10^{-7}	0.7	3.5×10^{-7}
5 W Gulf of Finland	4.4×10^{-7}	0.4	1.1×10^{-6}
6 E Gulf of Finland	5.2×10^{-7}	0.6	8.8×10^{-7}
7 E Baltic Proper	1.7×10^{-7}	0.7	4.4×10^{-7}
8 South of Gotland	0.8×10^{-6}	0.8	2.0×10^{-7}
9 Baltiysk	0	0	0
10 Slupsk Bank	3.3×10^{-7}	0.7	4.7×10^{-7}
11 North of Rügen	2.7×10^{-7}	0.7	3.8×10^{-7}
12 Fehmarn Belt	1.8×10^{-7}	0.7	2.7×10^{-7}
13 Little Belt	4.7×10^{-6}	0.5	8.7×10^{-6}
14 Great Belt	3.7×10^{-6}	0.4	8.4×10^{-6}
15 The Sound	3.2×10^{-6}	0.5	6.5×10^{-6}
16 Kattegat	9.4×10^{-7}	0.7	1.3×10^{-6}
Average	7.26×10^{-7}	0.6	1.21×10^{-6}

B.5 Weighting of the representative points

Table B-4 shows the relative weight assigned to the representative grounding points within each traffic area. The weight factor describes the probability that an accident occurring within the waterway section actually occurs at one specific representative point. The number of observed accidents per representative grounding point is comparatively small and is therefore used as a means of guidance when attributing the weights. The potential for groundings at places where no observations have been made during the last years was equally part of the considerations when attributing the specific weight factors.

Table B-4 *Weighting of the representative points*

Traffic area	Point no.	Name	Weight	Latitude	Longitude
1 Bothnian Bay	1	Örngrundet	0.2	65.27° N	22.02° E
	2	Etukari	0.2	65.67° N	24.20° E
	3	Kutumatala	0.15	65.10° N	25.10° E

Traffic area	Point no.	Name	Weight	Latitude	Longitude
	4	Maanahkiainen	0.2	64.63° N	24.22° E
	5	Mässkär	0.15	63.73° N	22.58° E
	6	Skotrevet	0.05	64.00° N	21.53° E
	7	Nordvalensgrund	0.05	63.54° N	20.77° E
2 Bothnian Sea and West of Gotland	1	Fjärdgrund	0.08	63.67° N	20.35° E
	2	Sjögrund	0.04	62.80° N	20.54° E
	3	Kristiinankaupunki	0.04	62.25° N	21.37° E
	4	Kupeli	0.06	61.64° N	21.33° E
	5	Leviamatala	0.06	61.10° N	21.35° E
	6	Hälsingskär	0.06	60.63° N	20.90° E
	7	Själstenarna	0.04	60.72° N	17.50° E
	8	Västeråsen	0.02	62.33° N	17.54° E
	9	Självgrunden	0.09	60.28° N	18.72° E
	10	Märbådan	0.12	60.03° N	19.88° E
	11	Norrfjärden	0.12	60.11° N	20.47° E
	12	Salvorev	0.03	58.02° N	19.35° E
	13	Deppö	0.03	57.15° N	18.05° E
	14	Örskärsbåden	0.03	57.47° N	16.82° E
	15	Gumbådarne	0.12	58.65° N	17.58° E
	16	Ingarö	0.06	59.22° N	18.60° E
3 E Gulf of Finland	1	Vysotsk	0.5	60.61° N	28.55° E
	2	Grekov bank	0.1	60.19° N	28.69° E
	3	Severnaya Moshchnaya Banka	0.15	60.13° N	27.87° E
	4	Severnyy Virgin	0.15	59.95° N	26.87° E
	5	Samoyed bank	0.1	59.88° N	28.22° E
4 W Gulf of Finland and Klints Bank	1	Skjaldholmsfjärden	0.15	60.23° N	21.67° E
	2	Rajakari	0.1	60.37° N	22.09° E
	3	Prisgrund	0.05	59.87° N	22.43° E
	4	Stenharun	0.1	59.80° N	21.32° E
	5	Hiiumadal	0.05	59.08° N	22.27° E
	6	Södra Skrikgrunden	0.05	57.15° N	18.52° E

Traffic area	Point no.	Name	Weight	Latitude	Longitude
	7	Hästgrund	0.025	59.91° N	24.16° E
	8	Harmaja	0.1	60.10° N	24.97° E
	9	Tunnholmen	0.1	60.19° N	25.77° E
	10	Ruotsinsalmi	0.05	60.47° N	27.01° E
	11	Ruamadal	0.025	59.71° N	26.11° E
	12	Prangli	0.05	59.60° N	25.00° E
	13	Keskmadal	0.05	59.59° N	24.65° E
	14	Krassi	0.05	59.36° N	23.79° E
	15	Tsernovimadal	0.05	59.20° N	23.31° E
7 E Baltic Proper	1	Kumarimadal	0.3	58.77° N	23.26° E
	2	Kihnumadal	0.05	58.06° N	23.91° E
	3	Randa	0.1	57.82° N	24.27° E
	4	Mihailova	0.3	57.75° N	21.75° E
	5	North of Klaipeda	0.25	55.90° N	21.01° E
6 South of Gotland	1	Utgrunden	0.3	56.36° N	16.27° E
	2	Norra Midsjöbanken	0.2	56.21° N	17.40° E
	3	Davids Banke	0.3	55.37° N	14.66° E
	4	Laxgrund	0.2	56.05° N	14.80° E
7 Slupsk Bank	1	Entrance of the Vistula Lagoon	0.02	54.65° N	19.86° E
	2	Gdansk Bay	0.4	54.45° N	18.69° E
	3	Off Swinoujscie	0.4	53.95° N	14.28° E
	4	Slupsk Bank	0.18	54.97° N	16.58° E
8 Baltic Sea Entrance and Arkona Sea	1	Svartgrund	0.01	55.24° N	14.25° E
	2	Nyker Rev	0.03	55.15° N	14.70° E
	3	Adler Grund	0.01	54.82° N	14.47° E
	4	Greifswalder Bodden	0.01	54.42° N	13.70° E
	5	Cape Arkona	0	54.69° N	13.43° E
	6	Kriegers Flak	0.01	55.05° N	13.03° E
	7	Gyldenløves	0.01	55.12° N	12.46° E
	8	Falsterborev	0.01	55.33° N	12.62° E
	9	Plantagenet Grund	0.005	54.65° N	12.80° E

Traffic area	Point no.	Name	Weight	Latitude	Longitude
	10	Gedser Rev	0.02	54.48° N	12.18° E
	11	Gammel Tolk	0.01	54.86° N	12.20° E
	12	Walküriengrund	0.005	54.11° N	11.04° E
	13	Øjet	0.005	54.62° N	11.15° E
	14	Kolberger Heide	0.005	54.45° N	10.31° E
	15	Issehoved	0.04	56.05° N	10.60° E
	16	Svanegrund	0.04	55.82° N	10.45° E
	17	Æbelø NW-Rev	0.01	55.65° N	10.16° E
	18	Odense Fjord	0.02	55.50° N	10.55° E
	19	Lyø W-Flak	0.02	55.05° N	10.09° E
	20	Bastholm Hage	0.03	55.30° N	9.77° E
	21	Lyngsodde Flak	0.04	55.52° N	9.74° E
	22	Hatter Rev	0.14	55.89° N	10.83° E
	23	Elefantgrund	0.07	55.53° N	10.92° E
	24	Agersø Flak	0.07	55.20° N	11.12° E
	25	South of Langenland	0.05	54.73° N	10.83° E
	26	Kogrund	0.02	54.97° N	11.65° E
	27	Kråsebænken	0.23	55.60° N	12.72° E
	28	Off Ven	0.03	55.89° N	12.64° E
	29	Off Ålsgårde	0.03	56.09° N	12.51° E
	30	Juelsgrund	0.02	55.45° N	12.34° E
9 Kattegat	1	Skagens Rev	0.1	57.76° N	10.71° E
	2	Off Hals	0.1	56.88° N	10.55° E
	3	Tangen	0.1	56.60° N	10.55° E
	4	Naveren	0.1	56.40° N	10.94° E
	5	Yderflak	0.1	56.07° N	11.02° E
	6	Store Middelgrund	0.05	56.55° N	12.07° E
	7	Fladen	0.05	57.18° N	11.74° E
	8	Off Gothenburg	0.2	57.66° N	11.71° E
	9	Tjörn	0.05	57.92° N	11.62° E
	10	Off Lysekil	0.05	58.26° N	11.44° E

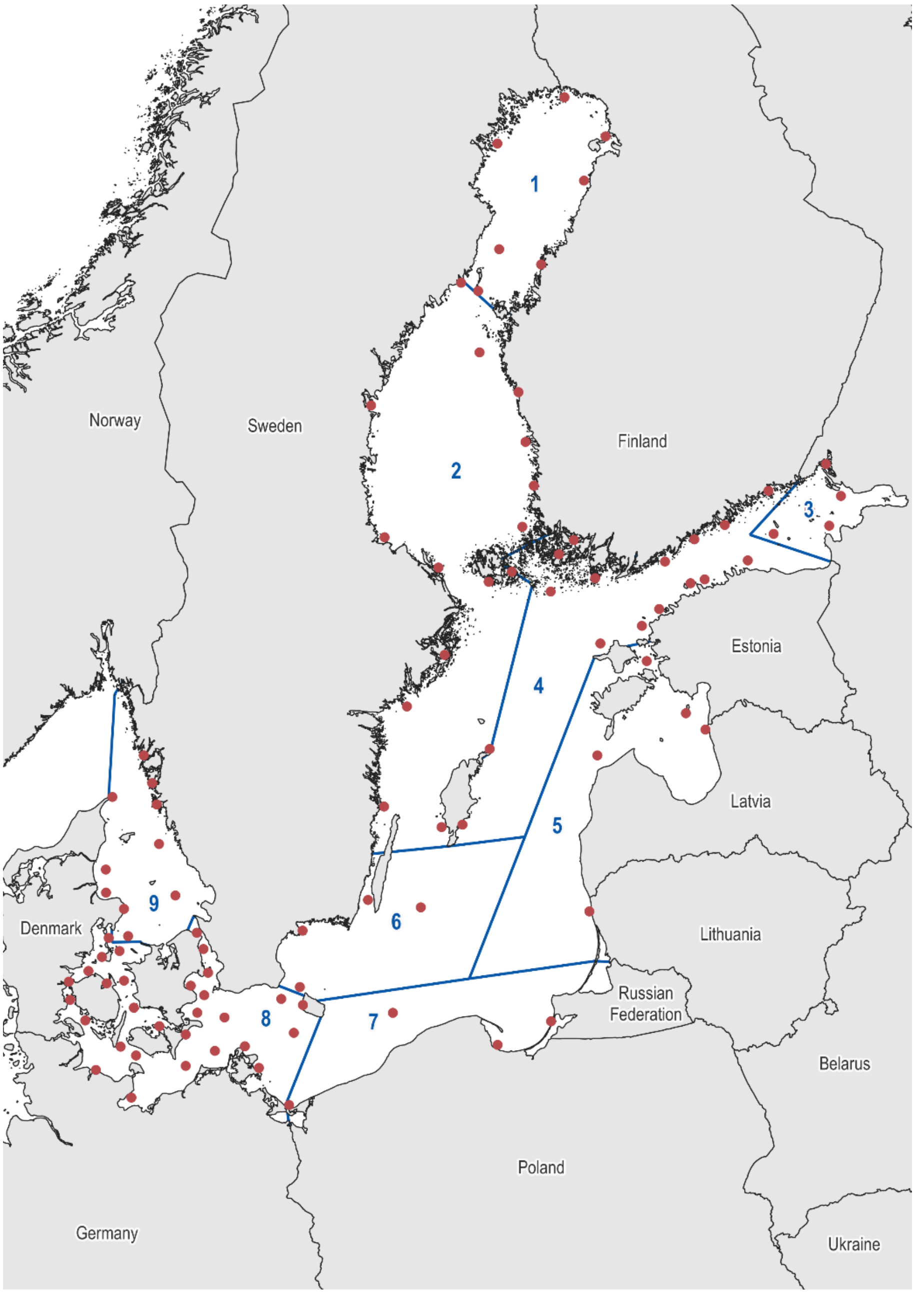

Figure B-2 *Overview of all representative grounding points*

B.6 Model overview

The yearly grounding frequency *F*(*t*,*s*,*k*) for a ship of ship type *t* and size class *s* at a grounding point *k* is determined as

$$F(t,s,k) = F_{basic}(i) \times w(i,k) \times m(t,s,i) \times \sum RRM(t,s,i)$$

Where

$F_{basic}(i)$ … the basic grounding frequency per sailed nautical mile in traffic area *i* *w*(*i,k*) ... the weight factor of representative grounding point *k*

m(*t,s,i*) ... the yearly number of sailed nautical miles with ships of type *t* and size class *s* in traffic area *i*

RRM(*t,s,i*) ... the risk-reduction factors of the RRMs that are in force for ships of type *t* and size class *s* in traffic area *i*

Appendix C Fraction of piloted ships

C.1 Introduction

The scope of this appendix is to estimate the fraction of piloted ships in the BRISK II project area.

The information in this memo is based on the following sources:

- Admiralty Sailing Directions (ASD), Baltic Pilot, containing Volume 1 (15th Edition, 2009) , Volume 2 (14th Edition, 2008) and Volume 3 (11th Edition, 2010)
- National pilotage rules and statistics provided by the BRISK II project countries

The BRISK II model differentiates between the reference years 2024 and 2036. However, there is no indications that pilotage rules and recommendations will be different between the two years. Thus, there is only one pilotage model that applies to both reference years.

There are various rules and recommendations for pilotage in place across the Baltic Sea. The rules are mandatory and have been issued by a specific country. The recommendations have been issued by IMO and "only" have recommendatory status.

Rules and recommendations can be split up into two main groups

- Rules and recommendations on deep-sea pilotage, see Section C.2
- Rules and recommendations on coastal pilotage, see Section C.3

The area of the Baltic Sea is divided into twenty pilotage areas for the purpose of this appendix, see Figure C-1. The areas are defined in accordance with the coverage area of the individual rules and recommendations presented in the following sections.

Figure C-1 The pilot areas used in the model

C.2 Deep-sea pilotage

The services of licensed deep-sea pilot are strongly recommended by the Baltic Pilotage authorities commission which recommends that:

- Masters of vessels which are constrained by their draught;
- Masters of vessels, other than those registered in one of the Baltic States, and who frequently navigate in the area;
- Masters of loaded oil and chemical tankers and gas tankers irrespective of their size;

should when bound to or from ports in Baltic Sea, avail themselves of the services of deep-sea pilots certified by the competent authority of a Baltic coastal state.

Areas covered

This includes areas 19 and 20.

Modelling

Ships in area 19 are assumed to have the same pilotage percentage as those transiting through the adjacent area 3, see section C.3.2.

Danish pilotage data show that some of the ships in the westernmost part of area 20 are using pilots, i.e. between Bornholm (area 6) and Kadetrenden (area 4). However, as no relevant information exists for the main part of area 20, it is assumed that no pilots are used. This is a simplified and conservative assumption.

C.3 Coastal pilotage

C.3.1 The Sound

IMO recommends that all tankers carrying oil cargos with draught of 7 meters or more, all chemical and gas tankers irrespective of size and ships carrying radioactive materials, shall apply for pilotage services established by the Government of Denmark and Sweden, when passing the sound within the area of Svinbådan Lighthouse-Hornbæk Harbour in the north and Skanör-Aflandshage (south point of Amager) in the south.

For ships calling at the ports facing the Sound, national pilotage rules for Denmark (cf. section C.3.2) and Sweden (cf. section 0) apply in addition to the above.

Areas covered:

This includes area 1 (Denmark) and area 8 (Sweden).

Modelling

The pilotage percentage in area 1 has been estimated by comparing the traffic volume at the Northern entrance of the Sound to the number of pilotage jobs in the Sound in 2024, see Table C-1. The traffic numbers are based on the traffic model (BRISK II, traffic analysis, 2025) whereas the pilotage numbers are based on statistics by DanPilot. Note that ingoing refers to ships going into the Baltic Sea (seen from a North Sea perspective), while outgoing refers to the opposite direction.

It needs to be stressed that these numbers are based on some simplifications, as it has not been possible to match traffic data and pilotage data one to one. It is assumed that the pilotage percentages from area 1 are a reasonable representation for the entire Sound. Thus, the numbers from area 1 are also applied to area 8.

Table C-1 Pilotage percentage in area 1 (Danish part of the Sound)

Pilotage area 1 ingoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	5%
2	500	3,000	0%	15%	0%	0%	1%	38%	1%
3	3,000	10,000	9%	29%	0%	0%	5%	30%	49%
4	10,000	25,000	25%	15%	4%	0%	21%	34%	0%
5	25,000	100,000	4%	0%	9%	0%	8%	33%	0%
6	100,000	-	0%	0%	23%	0%	0%	27%	0%

Pilotage area 1 outgoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	4%
2	500	3,000	0%	69%	0%	0%	3%	40%	4%
3	3,000	10,000	11%	91%	0%	0%	7%	30%	32%
4	10,000	25,000	33%	27%	12%	0%	27%	27%	9%
5	25,000	100,000	3%	0%	100%	0%	100%	100%	0%
6	100,000	-	0%	0%	100%	0%	100%	100%	0%

C.3.2 Denmark

This section covers the Danish coastal waters in general. Additional information on the Sound is provided in Section C.3.1.

The following national regulations apply:

- Pilotage is compulsory at all Danish harbours for the following vessels, unless exempted by law:
  - Loaded oil tankers of 1500 DWT or over
  - Loaded chemical tankers carrying dangerous liquid chemicals covered by IMO chemical code.
  - Gas tankers
  - Vessels carrying radioactive goods
  - Tankers with un-cleaned tanks not secured by inert gas

- Pilotage is compulsory for towed vessels for 150 GT and over, or 28 m LOA or more, navigating in dredged channels, marked navigation channels into harbours or where the towed ship is not manned or cannot be propelled by propelled by its engines.

- Pilotage is also compulsory for certain vessels within designated Danish harbours, fjords and bridges. Other Danish harbours strongly recommend the use of pilots.

In addition, the following IMO recommendations apply to Route T

- Pilotage is recommended for ships of 11 m draught or more

- Pilotage is recommended for ships carrying radioactive goods

Areas covered

This includes pilotage area 2 (Great Belt), 3 (Kattegat and Little Belt), 4 (Fehmarn Belt and Kadetrenden), 5 (waters around Møn) and 6 (waters around Bornholm).

Modelling

The pilotage percentage in area 2, 3, 4, 5 and 6 has been estimated by comparing the traffic volume at the Northern entrance of the Sound to the number of pilotage jobs in the Sound in 2024, see Table C-2 to Table C-6. The traffic numbers are based on the traffic model (BRISK II, traffic analysis, 2025) whereas the pilotage numbers are based on statistics by DanPilot. Note that ingoing refers to ships going into the Baltic Sea (seen from a North Sea perspective), while outgoing refers to the opposite direction.

As in Section C.3.1, it needs to be stressed that these numbers are based on some simplifications, as it has not been possible to match traffic data and pilotage data one to one. Amongst others, the analysis has focussed on pilotage in the open sea, i.e. ships in transit as well as ships to and from Danish ports where the pilot was used for a longer part of the voyage than just the port approach. This simplification is acceptable, as it essentially puts the focus on the large ships that constitute an actual spill risk.

Table C-2 Pilotage percentage in area 2 (Great Belt)

Pilotage area 2 ingoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	2%
2	500	3,000	0%	0%	0%	0%	1%	13%	7%
3	3,000	10,000	0%	6%	0%	0%	1%	52%	12%
4	10,000	25,000	1%	7%	0%	0%	2%	19%	100%
5	25,000	100,000	28%	0%	68%	2%	34%	85%	0%
6	100,000	-	100%	0%	91%	0%	0%	100%	0%

Pilotage area 2 outgoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	0%
2	500	3,000	0%	0%	0%	0%	0%	15%	6%
3	3,000	10,000	0%	5%	0%	0%	0%	19%	8%
4	10,000	25,000	0%	4%	0%	0%	1%	18%	100%
5	25,000	100,000	29%	0%	60%	0%	44%	85%	0%
6	100,000	-	100%	0%	100%	0%	0%	100%	0%

Table C-3 Pilotage percentage in area 3 (Kattegat and Little Belt)

Pilotage area 3 ingoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	3%
2	500	3,000	0%	0%	0%	0%	0%	100%	1%
3	3,000	10,000	0%	1%	1%	0%	1%	41%	12%
4	10,000	25,000	0%	5%	0%	0%	1%	16%	21%
5	25,000	100,000	15%	0%	21%	2%	4%	84%	0%
6	100,000	-	100%	0%	38%	0%	0%	100%	0%

Pilotage area 3 outgoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	0%
2	500	3,000	0%	0%	0%	0%	1%	75%	3%
3	3,000	10,000	0%	2%	3%	0%	0%	25%	0%
4	10,000	25,000	0%	2%	0%	0%	0%	15%	27%
5	25,000	100,000	19%	0%	33%	2%	9%	70%	0%
6	100,000	-	100%	0%	66%	0%	0%	100%	0%

Table C-4 Pilotage percentage in area 4 (Fehmarn Belt and Kadetrenden)

Pilotage area 4 ingoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	0%
2	500	3,000	0%	0%	0%	0%	0%	1%	0%
3	3,000	10,000	0%	1%	0%	0%	0%	0%	6%
4	10,000	25,000	0%	12%	0%	0%	0%	0%	33%
5	25,000	100,000	14%	0%	20%	0%	7%	55%	0%
6	100,000	-	100%	0%	83%	0%	0%	100%	0%

Pilotage area 4 outgoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	0%
2	500	3,000	0%	0%	0%	0%	0%	0%	3%
3	3,000	10,000	0%	1%	0%	0%	0%	0%	0%
4	10,000	25,000	0%	18%	0%	0%	0%	1%	75%
5	25,000	100,000	22%	0%	100%	0%	52%	100%	0%
6	100,000	-	100%	0%	54%	0%	0%	86%	0%

Table C-5 Pilotage percentage in area 5 (waters around Møn)

Pilotage area 5 ingoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	0%
2	500	3,000	0%	0%	0%	0%	0%	0%	0%
3	3,000	10,000	0%	1%	0%	0%	0%	0%	5%
4	10,000	25,000	0%	3%	0%	0%	0%	0%	0%
5	25,000	100,000	0%	0%	5%	0%	0%	29%	0%
6	100,000	-	31%	0%	0%	0%	0%	48%	0%

Pilotage area 5 outgoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	0%
2	500	3,000	0%	0%	0%	0%	0%	0%	4%
3	3,000	10,000	0%	0%	0%	0%	0%	0%	0%
4	10,000	25,000	0%	0%	0%	0%	0%	0%	0%
5	25,000	100,000	0%	0%	1%	0%	1%	5%	0%
6	100,000	-	0%	0%	0%	0%	0%	16%	0%

Table C-6 Pilotage percentage in area 6 (waters around Bornholm)

Pilotage area 6 ingoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	0%
2	500	3,000	0%	0%	0%	0%	0%	0%	0%
3	3,000	10,000	0%	1%	0%	0%	0%	0%	2%
4	10,000	25,000	0%	5%	0%	0%	0%	0%	0%
5	25,000	100,000	0%	0%	1%	0%	0%	12%	0%
6	100,000	-	48%	0%	0%	0%	0%	46%	0%

Pilotage area 6 outgoing

Size class	DWT min	DWT max	Container ship	Cruise ship	Dry bulk	Ferry & Roro	General cargo	Liquid bulk	Others
1	0	500	0%	0%	0%	0%	0%	0%	0%
2	500	3,000	0%	0%	0%	0%	0%	0%	2%
3	3,000	10,000	0%	0%	0%	0%	0%	0%	0%
4	10,000	25,000	0%	0%	0%	0%	0%	0%	0%
5	25,000	100,000	0%	0%	1%	0%	1%	11%	0%
6	100,000	-	48%	0%	0%	0%	0%	47%	0%

C.3.3 Sweden

This section covers the Swedish coastal waters in general. Additional information on the Sound is provided in Section C.3.1.

Pilotage is compulsory in Swedish coastal waters for the vessels meeting one of the below criteria:

- vessel length of 70 meters or more,
- vessel breadth of 20 meters or more.
- vessels carrying one the following cargoes
  - Irradiated nuclear fuel, plutonium or high-level radioactive waste.
  - Bulk cargo consisting of liquid substances belonging to MARPOL category X, Y or Z.
  - Liquefied gas in accordance with the IGC-code.
  - Single-hull tankers carrying petroleum products and having a length of 50 meters or more.

Areas covered

The areas which are covered by these regulations include area 7 (Swedish Kattegat coast), area 9 (South-East Coast of Sweden), area 10 (Öland) and area 12 (Gulf of Bothnia-Western shore).

It is assumed that the pilotage percentages from area 3 are a reasonable representation for the entire Kattegat. Thus, the numbers from area 3 are also applied to area 19. Note, however, that area 7 (Swedish coastal zone in the Kattegat) is modelled separately, cf. Section C.3.3.

Modelling

All ships are assumed to comply with the mandatory rules.

C.3.4 Germany

Pilotage is compulsory for all following vessels in the German harbours.

- Tankers carrying gas, chemicals petroleum or petroleum products.
- Unloaded tankers if not cleaned, gas-freed or completely inerted, after having petroleum or petroleum products with a flash point below 35 degree centigrade.
- Stralsund North approach- other vessels over 60 m LOA, 10 m beam or 3.3 m draught.
- Stralsund East approach- other vessels over 85 m LOA, 13 m beam or 5 m draught.

These regulations also apply to Sassnitz/Mukran and Wolgast, for which pilotage is provided by Stralsund.

Areas covered

The areas belonging to the individual port approaches are not marked separately in Figure C-1.

Modelling

All ships are assumed to comply with the mandatory rules.

C.3.5 Poland

Pilotage is compulsory in all Polish ports for the following vessels, unless a specific exemption has been granted.

- All vessels with a length of 40 m or over.
- All vessels carrying dangerous cargos regardless of size.
- Any vessels which is damaged and any vessel, which through exceptional circumstances, may create a danger to navigation or threat to environment.

Area covered

The areas belonging to the individual port approaches are not marked separately in Figure C-1. The Gulf of Gdansk is defined as pilotage area 18.

Modelling

All ships are assumed to comply with the mandatory rules.

C.3.6 Russia

Note that this section is based on BRISK I, where Russia contributed via the BRISK-RU project.

Pilotage is compulsory for all foreign vessels entering, leaving or shifting within ports in Russia which are open to foreign trade. Special regulations are in force with regard to naval vessels. Deep-sea Pilots can be requested from Sankt Petersburg.

Area covered

These regulations cover some portion of the Gulf of Gdansk (pilotage area 18) and small portion of the Gulf of Finland in (pilotage area 14 and 15).

Modelling

All ships are assumed to comply with the mandatory rules. For modelling purposes, it is assumed that pilotage is applied to all vessels, i.e. not just foreign vessels.

C.3.7 Lithuania

Pilotage is compulsory for all vessels entering, leaving or shifting within ports in Lithuania.

Areas covered

The areas belonging to the individual port approaches are not marked separately in Figure C-1.

Modelling

All ships are assumed to comply with the mandatory rules.

C.3.8 Latvia

Pilotage is compulsory for all vessels entering, leaving or shifting within ports in Latvia.

Area covered

This includes shore area within Gulf of Riga (pilotage area 17).

Modelling

All ships are assumed to comply with the mandatory rules.

C.3.9 Estonia

Pilotage is compulsory for all foreign vessels within the inner territorial waters of Estonia. Such vessels my only proceed in established shipping routes or channel. However, within the Gulf of Riga, the use of established shipping routes or channel is permissible without the services of a pilot. Pleasure craft with a length under 24 m are exempt from these regulations.

Pilotage is compulsory for all vessels in the coastal zone of the Southern shore of the Gulf of Finland.

Area covered

This includes shore areas within the Gulf of Riga (pilotage area 17), the western approaches including Saaremaa and Hiiumaa (pilotage area 16) and the southern shore of the Gulf on Finland (area 15).

Modelling

All ships are assumed to comply with the mandatory rules.

C.3.10 Finland

Pilotage is generally compulsory within Finnish inner territorial waters for vessels with a length exceeding 50 metres. A number of additional, location-specific rules exist.

Area covered

This includes the Eastern shore of the Gulf of Bothnia (pilotage area 13) and the Northern shore of the Gulf of Finland (area 14).

Modelling

All ships are assumed to comply with the mandatory rules.

Appendix D Collisions with fixed objects and anchoring ships

D.1 Introduction

This memo addresses the spill risk in the Baltic Sea associated with ship collisions with fixed objects, offshore platforms and offshore oil transfer operations during 2024.

The following spill risks are considered in the present note.

Spills from:

- Offshore oil platforms

- Offshore oil transfers, namely:
  - - Ship to ship (STS) operations
  - - Bunkering activity at sea
  - - Offshore oil terminal activity

- Ship collision with wind turbines

In accordance with BRISK I (BRISK I, Spill, 2012), ship collisions with lighthouses and bridges are assessed to contribute negligibly to the overall oil spill risk in the Baltic Sea and are therefore excluded from the present assessment.

The spills can occur as a result of:

1. Operation of the considered facility

2. A collision of a passing merchant vessel with the considered facility

3. A collision of a dedicated vessels with the considered facility

4. Fire on a tanker with subsequent hatch wall failure

The spill size has been categorised according to the spill size scheme, as shown Table D-1. The scheme provides mutually exclusive classes that are specified by a low, a representative and a high value.

Table D-1 Applied spill size scheme

Spill Sizes				
Spill Size	Low	Representative	High	Spill Description
0	0	0	0	No spill
1	0	0.3	1	0 - 1t (0.3t)
2	1	4	15	1t - 15t (4t)
3	15	67	300	15t - 300t (67t)
4	300	1,200	5,000	300t - 5,000t (1,200t)
5	5,000	8,700	15,000	5,000t - 15,000t (8,700t)
6	15,000	27,000	50,000	15,000t - 50,000t (27,000t)
7	50,000	87,000	150,000	50,000t - 150,000t (87,000t)

D.2 Offshore Oil Production Platforms

D.2.1 Background

In BRISK II, the same offshore oil platforms as those considered in BRISK I are included in the assessment. This is due to the fact that no updated platform information has been provided for BRISK II. Consequently, the same platforms and the same input information as applied in BRISK I are used in the present analysis.

Accordingly, the three platforms considered, as in BRISK I, are Baltic Beta, PG-1, and MLSP D-6.

Baltic Beta (Poland)

The 1977 built *Baltic Beta* is a three-legged jack-up driller converted into a production platform. It offloads production to the tanker, Icarus II, via a mooring buoy.

The platform is located 55.479°N latitude 18.180°E longitude 37 nm north of Rozewie. The collision diameter has been provided as 35 m. There are estimated 600 t of oil in storages and pipes on the platform. No critical situation with passing vessels has been observed so far.

PG1 (Poland)

The platform is located 55.456° N latitude 18.157° E longitude 37 nm north of Rozewie. The collision diameter has been provided as 10 m. There are estimated 400 t of oil in storages and pipes on the platform.

MLSP D-6 (Russia)

Lukoil operates an offshore oil platform in the Russian EEZ. The MLSP D-6 platform is located 36 nm north of the city Kaliningrad at 55.316° N latitude, 20.579° E longitude. The depth of the water is 25 m to 35 m.

The development complex consists of two platforms which are about 11 m above sea level. A bridge of about 70 m links them. One platform bears the living quarters, including a helideck, the other contains the process and drilling system.

The risk contribution has been obtained for the Russian platform as an aggregated figure. For the Polish platforms it has been considered that the spill risk is composed of the spill risk due to operation and to ship collision where it is differentiated into collisions with dedicated supply vessels and passing merchant vessels.

D.2.2 Russian platform

Information for the Russian platform has been provided as an aggregated risk. The estimated size of spill from offshore platforms has been provided to be 1,500 t to maximal 5,000 t. The provided estimate for the spill frequency is 1.0 × 10^{-3} per year.

The risk matrix is shown in the table below. Based on this, the estimated average annual oil spill risk is 1.2 t per year.

Table D-2 Platform Spill frequency for the Russian platform

	Spill frequency in 1/10,000 years				
Area	0 - 1 t	1 - 15 t	15 - 300 t	300 - 5,000 t	Total
Russia	-	-	-	10.0	10.0
Total	-	-	-	10.0	10.0

D.2.3 Polish platforms

Spills from operation

In BRISK I, the risk of oil spills from platform operations was assessed based on spill statistics from the HELCOM database, with the Danish OILOPS database (OILOPS, 2011) used as a sensitivity check. The analysis showed consistent spill frequencies across the two databases and indicated that operational spills are predominantly small, with only a very limited contribution from larger spill classes.

As shown in Figure 4-1, the number of operational oil spills has remained relatively stable since around 2004, indicating no significant change in spill occurrence over this period. This stability suggests that neither operational practices nor the underlying spill mechanisms have changed substantially. Based on the observed stability in spill occurrence, the results of the BRISK I analysis (BRISK I, Spill, 2012) are retained for BRISK II, as summarised in Table D-3.

Table D-3 Spill risk from operation for the Polish platforms

	Spill frequency in 1/10,000 years		
Area	0 - 1 t	1 - 15 t	Total
Platform operation	12,568	1,396	13,964
Total	12,568	1,396	13,964

Passing vessel collision

Merchant vessels sail in the vicinity of the platforms. They might get off-course and head towards the platform. The platforms are marked in the navigation charts and a standby vessel is in the vicinity and might contact an aberrant vessel and inform it that it sails off its course.

The probability of collision is based on the ship traffic in the vicinity. The collision probability has been estimated based on the model which is described in Section D.5.1.

According to BRISK I (BRISK I, Spill, 2012), a spill probability of 33 % is assumed in case of a merchant vessel colliding with a platform.

If a platform collapses then it may collapse so that the oil stored on the platform, in the risers and in the pipelines will be spilled. Based on BRISK I (BRISK I, Spill, 2012), it is assumed to be equally likely that the spilled amount is between 15-300 t or between 300-5,000 t.

If subsea valves fail to operate during an emergency, continued leakage from the well may occur, and the maximum spill size category is therefore applied. The probability of valve failure is assumed in accordance with BRISK I (PFD = 0.55%). Information is provided that there are 7 risers. It is further assumed that each riser goes to a well and that all subsea valves have to perform independently in order not to cause a well to spill. The probability for a positive performance of all valves is 96.2%, i.e. for a bad performance of one or more valves it is 3.8%.

Dedicated vessels

In BRISK I, the spill risk from collisions with dedicated vessels (supply vessels and standby vessels) was assessed based on collision rates reported for Danish offshore platforms. For BRISK II, the same methodology, assumptions, and spill risk estimates as derived in BRISK I are applied. As the operational pattern of dedicated vessels and their interaction with the platforms are not expected to change significantly, the analysis results from BRISK I are retained and used unchanged, as summarised in Table D-4.

Table D-4 Spill frequency from collisions with dedicated vessels for the Polish Platforms

	Spill frequency in 1/10,000 years							
Area	0 - 1 t	1 - 15 t	15 - 300 t	300 - 5,000 t	5,000 - 15,000 t	15,000 - 50,000 t	50,000 - 150,000 t	Total
PL Platforms	-	-	28.19	2.98	-	-	0.23	31.41
Total	-	-	28.19	2.98	-	-	0.23	31.41

D.3 Offshore Oil transfer

Oil is transferred offshore in the Baltic Sea at several locations and at different types of facilities and with different amounts of oil being transferred. The following types of oil transfers at sea are considered.

- Ship-to-ship (STS) operations
- Offshore bunkering
- Offshore oil terminal

The applied data are described separately in the data report.

D.3.1 Ship-to-ship operations (STS operations)

A detailed description of STS operations is provided in the BRISK I report (BRISK I, Spill, 2012). The present memo therefore focuses on the differences compared to the BRISK I reference situation and the updated 2024 data.

Denmark and Sweden are the only countries where such operations occurred during 2024. Histrotically, these transfers typically occurred north of the Great Belt, which is too shallow for being used by some crude oil tankers when fully loaded. These tankers pass the Great Belt partly loaded and receive additional cargo from a feeder ship after the passage. In recent years, other locations have become relevant as well, see Table D-5. Only locations with more than 10 operations are included, as locations with fewer operations represent sporadic activity and are not considered representative.

Table D-5 Summary of STS operations in 2024

Area	No. STS Operation (2024)	Latitude	Longitude
Frederikshavn (DK)	20	57° 28' 50" N	10° 42' E
SEGOT - Göteborg (SE)	63	57° 34.451' N	11° 33.164' E
SELLA – Luleå (SE)	11	65° 24.972' N	22° 57.120' E
SE069 – Nord Ven (Helsingborg) (SE)	12	55° 56' 0" N	12° 41' 0" E
Total	*106*	-	-

The following main hazards have been identified:

- Spill from operation due to hose rupture or overfilling.
- Spill resulting from a collision with a dedicated vessel (feeder ships)
- Spill resulting from a collision with a passing vessel (passing merchant vessels)

Spill from operation

Due to limited availability of detailed information on individual ship-to-ship (STS) operations in 2024, a direct re-estimation of spill frequencies is not possible. For the present assessment, the spill frequencies associated with operational failures are therefore adapted from the BRISK I study.

In BRISK I (BRISK I, Spill, 2012), the average frequency of spills resulting from operational failures during STS operations was estimated to be approximately 8 spills per 10,000 years of operation, based on historical experience. This range is considered to provide a reasonable order-of-magnitude estimate for operational spill events in the absence of updated detailed data. Accordingly, the same spill frequency per operation is applied in the present assessment, while the overall risk level is adjusted to reflect the updated number of STS operations observed in 2024.

The following spill size distribution (in case a spill occurs) has been selected in BRISKI: 40.0% (0-1 t), 39.0% (1-15 t), 20.0% (15-300 t), 1.0% (300-5,000 t).

The final spill frequencies are summarised in Table D-6.

Table D-6 Spill frequencies in 1/10,000 years from operation errors

Area	0-1t	1-15t	15-300t	300-5,000t	Total
Frederikshavn (DK)	56	54.6	28	1.4	140
SEGOT - Göteborg (SE)	176.4	172	88.2	4.4	441
SELLA – Luleå (SE)	30.8	30	15.4	0.8	77
SE069 – Nord Ven (Helsingborg) (SE)	33.6	32.8	16.8	0.8	84
Total	*296.8*	*289.4*	*148.4*	*7.4*	*742*

Spill from collisions with dedicated vessels

Feeder ships approach the mother ship prior to the transfer operation in order to deliver cargo. During this approach phase, there is a potential risk of collision between the feeder ship and the receiving vessel. As detailed information for re-estimating this risk is not available for the present assessment, the spill frequency from collisions with dedicated vessels is adapted from the BRISK I results.

In BRISK I (BRISK I, Spill, 2012), the spill frequency associated with collisions involving dedicated feeder vessels during STS operations was estimated to be in the order of 0.11 per 10,000 years of operation. This value is therefore applied in the present assessment. In case a spill occurs, the following spill size distribution has been selected: 66.0% (300-5,000t), 21.0% (5,000-15,000t), 8.0% (15,000-30,000t), 5.0% (50,000-150,000t). This distribution represents an average value derived from the BRISK I results.

The estimated spill frequencies are summarised in Table D-7

Table D-7 Spill frequencies in 1/10,000 years from collisions with feeder ships

Area	300-5,000t	5,000-15,000t	15,000-30,000t	50,000-150,000t	Total
Frederikshavn (DK)	1.45	0.46	0.18	0.11	2.20
SEGOT - Göteborg (SE)	4.57	1.46	0.55	0.35	6.93
SELLA – Luleå (SE)	0.80	0.25	0.10	0.06	1.21
SE069 – Nord Ven (Helsingborg) (SE)	0.87	0.28	0.11	0.07	1.32
Total	*7.70*	*2.45*	*0.93*	*0.58*	*11.66*

Spill from collisions with passing vessels

Passing merchant vessels may collide with ships that are involved in STS operations. The collision model described in Section D.5.1 is used to estimate the collision frequencies. The model estimates such frequencies for objects that are present all year round. This is not the case for ships involved in STS operations. Therefore, a ratio is introduced in accordance with the duration of STS activities, see Table Table D-8.

Owing to limited data on the duration of individual STS operations in Swedish waters, a representative average duration of 2 days is applied.

Table D-8 Likelihood of an ongoing STS operation at the considered location

Area	Ratio
Frederikshavn (DK)	6.22%
SEGOT - Göteborg (SE)	34.52%
SELLA – Luleå (SE)	6.03%
SE069 – Nord Ven (Helsingborg) (SE)	6.58%

The spill probability is closely following the model described in Section D.5.2. It is assumed that 10% of the collisions with a tanker lead to spill of oil. In 30% of the spills, it is only bunker oil that is spilled. In 70% of the cases the penetration into the rammed ship is such that cargo is spilled.

The average total bunker volume for a 100,000 and 300,000 DWT ship is 3,100 and 7,300 t, respectively. This volume is distributed over two or more bunker tanks. A collision of a passing vessel may result in a collision with the mother ship or with the feeder ship. If the bunker oil tank is hit above the sea level then only a part of the tank volume is spilled. Moreover, the tank might not be completely full with bunker oil. The applied model considers that if bunker oil is spilled, then the spill will be either larger than 15 t and smaller than 300 t or larger than 300 t but smaller than 5,000 t. These two scenarios are considered to be equally likely.

The spill size for the case when cargo is spilled is based on the ship geometry of typical 100,000, 200,000 and 300,000 DWT ships. Based on these, the cargo hold size is estimated (9,700, 16,300 and 26,200 m^3). It is assumed equally likely that the rammed tanker is one of the three tankers. Finally, it is assumed to be equally likely that a single hold or that two holds are hit. Foundering is less likely but covered by the application of the applied spill size categories.

D.3.2 Bunkering of oil offshore

Bunkering is transfer of oil products to a ship where the transferred oil products are used for the operation and propulsion of the ship. During 2024, 2,865 bunker operations were reported in Danish waters, which corresponds to 7.85 per day. 98.6% of the operations were carried out in Ålbæk Bay, which therefore represents the dominant bunkering area in Denmark. The remaining 1.4% of bunker operations were distributed among several other locations, The remaining 1.4% of bunker operations were distributed among a few other identified locations, including Åbenrå Fjord, Kalundborg Fjord, Århus Bay, and Læsø. In addition, a small number of operations were reported under “Other”, for which no specific geographical location was provided in the available data.

During this period, 1.15 million tons were transferred which corresponds to 3,154 tons per day and 402 t per operation. 98.8% of the tonnage was transferred at Ålbæk Bay.

The same hazards as for STS operations have been identified. The identified main hazards are:

- Spill from operation including spill from hose rupture and spill from overfilling.
- Spill resulting from a collision with a dedicated feeder ships
- Spill resulting from a collision with a passing merchant vessels

Spill risk from operation

The transfer of bunker oil can result in spill of oil products into the sea. Typical errors leading to spills are failure of a hose, overfilling or wrong handling of equipment.

According to BRISK I (BRISK I, Spill, 2012), the average pump capacity is assumed to 400 m^3/h. It is further assumed that if an overfilling happens, then 2 t of the product may stay on the ship deck. This means that 1t is spilled into the sea after 27s, 15t after 2.5 min and 300 t after 45 min. Based on observations it is concluded that every 3,600th operation leads to a spill from operation. Of the 9 reported spills, 8 were smaller than 1 t. One spill was in the size of 3 t. However, this spill might have wrongly attributed to bunkering. This makes the following model conservative: It is assumed 10% of the spills are between 1 and 15 t. In 1% of the cases the pump is stopped after 2.5 minutes which corresponds to a spill of larger than

15 t. Spills larger than 300 t are considered with a ratio of 0.1% which is conservative because this requires that the pump is operated for 45 minutes. 300 t also represents the major part of a typical single bunker transfer. The remaining spills (89%) correspond to releases smaller than 1 t . Finally, it is considered that the simple risk model also covers hose failure. Hose failure has an occurrence rate which is estimated to be a magnitude smaller than for overfilling and also the consequence size distributions are comparable for these hazards.

The final spill frequencies are summarised in the Table D-9. The total frequency is 0.8 times per year.

Table D-9 Spill frequencies in 1/10,000 years from operation errors

Area	0-1t	1-15t	15-300t	300-5,000t	5,000-15,000t	Total
Åbenrå Fjord	13	1	0	0	0	14
Ålbæk Bugt	7,069	795	80	8	0	7,952
Århus Bugt	8	1	0	0	0	8
Kalundborg Fjord	10	1	0	0	0	11
Læsø	10	1	0	0	0	11
Other area	35	4	0	0	0	39
Total	*7,145*	*804*	*80*	*8*	*0*	*8,037*

Spill risk from collisions with dedicated vessels

The risk modelling applied in BRISK I (BRISK I, Spill, 2012) is followed closely. A contact frequency of 4 events per 32,000 approaches is applied for bunkering operations, corresponding to 1.25×10^{-4} per approach.

In Section D.5.2, it is estimated that 3% of the ship-ship collisions will lead to leakage of bunker oil and in 7% of ship-ship collisions involving tankers, there will be spill of cargo oil. These probabilities are adopted from ship-ship collision where the kinetic impact energy is higher. Feeder ships involved in bunker operations approach, however, at a much lower speed. Moreover, such vessels are smaller vessels (typically 4,000 DWT, 80m LOA). Due to this it is assumed that only every second collision will be a collision where the conditions are comparable to ship-ship collisions where bunker oil is spilled. For cargo spills it is assumed that only in every tenth collision there is kinetic energy enough that there is a risk of cargo spill. The fraction of tankers among the ships is taken to be 26%.

The amount of bunker oil spilled in case of a collision is assumed equally likely to be 15-300 t or 300-5,000 t.

The spill size distribution for spills of cargo oil is taken to be similar to the distribution assumed in (BRISK I, Spill, 2012). The assumed distribution is: 300-5,000 t (25%); 5,000 -15,000 t (50%); 15,000 -50,000 t (24%); 50,000-150,000 t (1%).

The spill risk from collisions with feeder ships is estimated to 10.89 tons per year and 60 spills in 10,000 years.

Table D-10 Spill frequencies from collisions with feeder ships per 10,000 years

Area	15-300t	300-5,000t	5,000-15,000t	15,000 - 50,000 t	50,000 - 150,000 t	Total
Åbenrå Fjord	0.0	0.0	0.0	0.0	0.0	0.1
Ålbæk Bay	26.5	28.0	3.1	1.5	0.1	59.2
Århus Bay	0.0	0.0	0.0	0.0	0.0	0.1
Kalundborg Fjord	0.0	0.0	0.0	0.0	0.0	0.1
Læsø	0.0	0.0	0.0	0.0	0.0	0.1
Total	*26.7*	*28.2*	*3.1*	*1.5*	*0.1*	*59.5*

Spill risk from collisions with passing vessels

Passing vessels may collide with the ships that are involved in bunkering operations. The collision model described in Section D.5.1 is used to estimate the collision frequencies. As 98.6% of bunkering operations are located in Ålbæk Bay, only Ålbæk Bay is considered in the assessment of collision risk with passing vessels.

The spill frequency is closely following the model described in Section 8.2. It is assumed that 10% of the collisions lead to spill of oil. In 30% of the spills, it is only bunker oil that is spilled. In 70% of the cases the penetration is such that cargo is spilled. It is assumed that in 25% of the cases the ship is a tank ship. For other ships it is considered that bunker oil is spilled in 3% of the cases.

The amount of bunker oil is assumed to be equally likely to be between 15-300 t or between 300-5,000 t. The spill size distribution for tanker loading is taken to be the same as for spill risk from tanker hit by a dedicated vessels i.e.: 300-5,000 t (25%); 5,000 -15,000 t (50%); 15,000-50,000 t (20%); 50,000-150,000 t (5%).

D.3.3 Offshore oil terminal

The Butinge offshore oil terminal is located at 56.047° N and 20.960° E approx. 7 km (3.8 nm) west of Sventoji. The terminal is in operation all-year-round and provides crude oil to the Mazeikiai Refinery.

The identified main hazards are:

- Spill from operation including spill from hose rupture and spill from overfilling
- Spill resulting from a collision with a passing vessel

Spills from operation

As no updated information is available, the methods and results for spills from operation are adopted directly from BRISK I.

Overfilling is considered to be the main contributor and consequences from hose failure are considered to be covered with the applied simple modelling.

The rate of overfilling is taken as 9 overfillings in 32,000 operations which is based on observations from bunkering activities. With 89 annual operations the total spill frequency is estimated to 2.5 × 10^{-2} per year.

In case of an overfilling, a ratio of oil will remain on the deck. This amount is assumed to be in the order of 5 t. This leaves a reaction time of 3 seconds. Larger reaction times will lead to a spill into the sea. If the reaction time is larger than 15 seconds, more than 15 tons are spilled and after more than 3.5 min more than 300 t are spilled. More than 5,000 t are spilled, if the pump has not been stopped for more than an hour.

Based on these reaction time criteria the following spill size distribution (in case a spill occurs) has been selected: 20.0% (0-1 t), 55.0% (1-15 t), 24.0% (15-300 t), 1.0% (300-5,000 t).

Passing vessel risk

The buoy is visited by tankers in the size of 100.000 to 120.000 DWT tankers which are about 250 m long. The collision diameter is therefore taken as 250 m. The likelihood of an ongoing operation is 28%. This is roughly based on 100 ship visits per year and with one visit lasting one day.

The collision frequency from passing vessels is estimated to 1.5 × 10^{-4} per year.

The spill frequency is following closely the model described in Section D.5.2. It is assumed that 10% of the collisions lead to spill of oil. In 30% of the spills, it is only bunker oil that is spilled. In 70% of the cases the penetration is such that cargo is spilled.

The average total bunker volume for a 100,000 DWT tanker is 3,100 t. This volume is distributed over two or more bunker tanks. If the bunker oil tank is hit above the sea level, then only a ratio of the tank is spilled. Moreover, the bunker tank might not be completely filled. The applied model considers that if bunker oil is spilled, then the spill will be either smaller than 300 t or smaller than 5,000 t. These scenarios are considered to be equally likely.

The spill size for the case when loading is spilled is based on the ship geometry of a typical 100,000 DWT ship. Based on this, the cargo hold size is estimated to 9,700 m^3. It is also assumed that it is equally likely that half or the full cargo in the affected cargo compartment is spilled. Finally, it is assumed to be equally likely that a single hold or that 2 holds are hit. Foundering is less likely but covered by the application of the applied spill size categories.

D.4 Wind turbines

Several offshore wind farms (OWFs) will be constructed between the reference year 2024 and the prognosis year 2036, see Figure D-1. Routes intersecting planned OWFs are coloured red, whereas routes intersecting potential OWFs (i.e. OWFs that have not been approved by the authorities yet) are not highlighted. Potential OWFs are only shown for information purposes but not considered in the model.

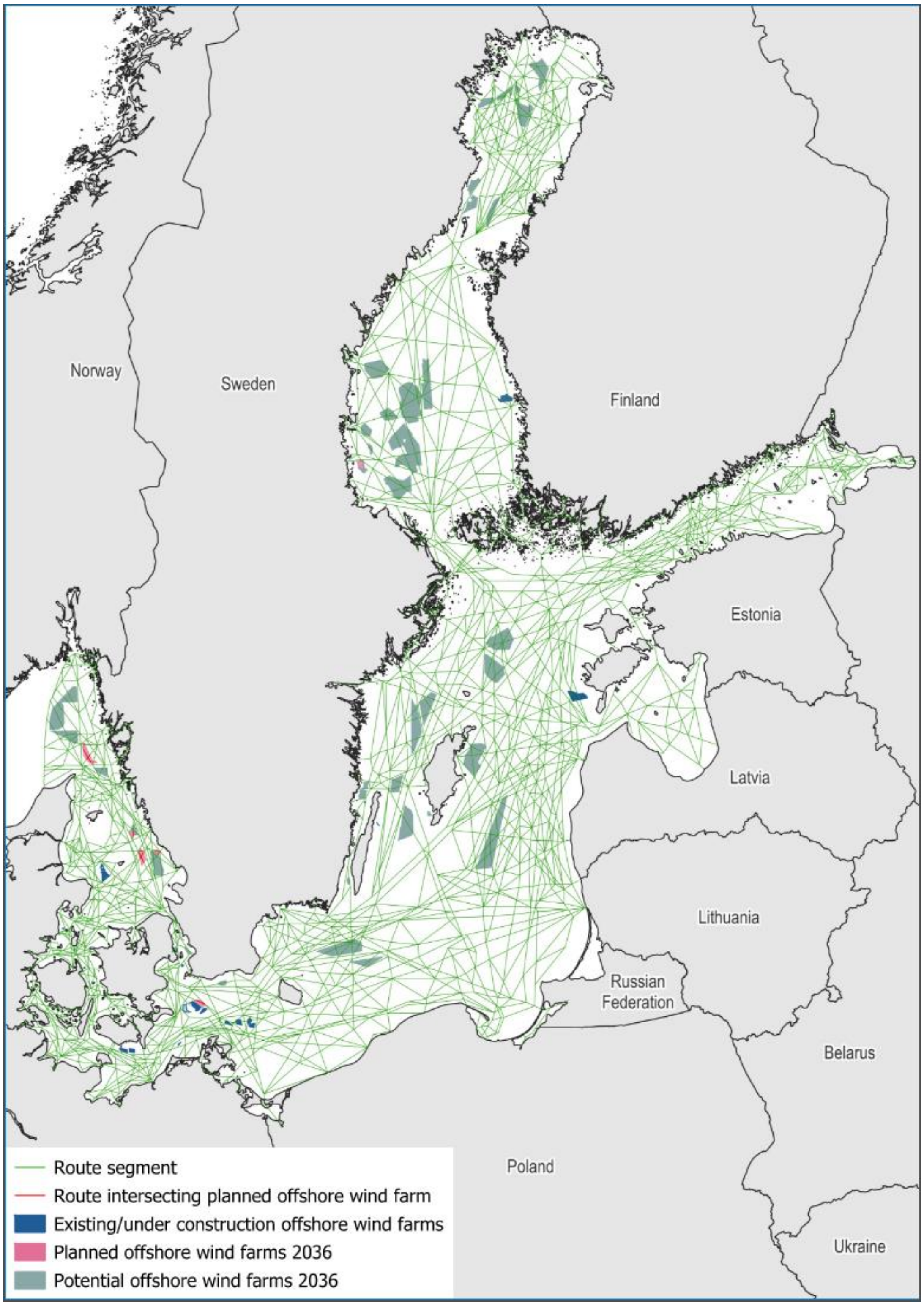

Figure D-1 Offshore wind farms, existing in 2024 and planned for construction fore 2036

In the following, the model for estimating the risk of oil spill due to ship collisions is described. The collision model described in Section D.5.1, which is based on Fujii's model (see Section 3.2.1) is used to estimate the collision frequencies.

Each offshore wind farm is simplified and represented by its boundary geometry, and the collision frequency is defined as the frequency of a vessel intersecting this boundary, see Figure D-2. Only route segments intersecting or located within a defined influence distance from the wind farm are considered in the analysis.

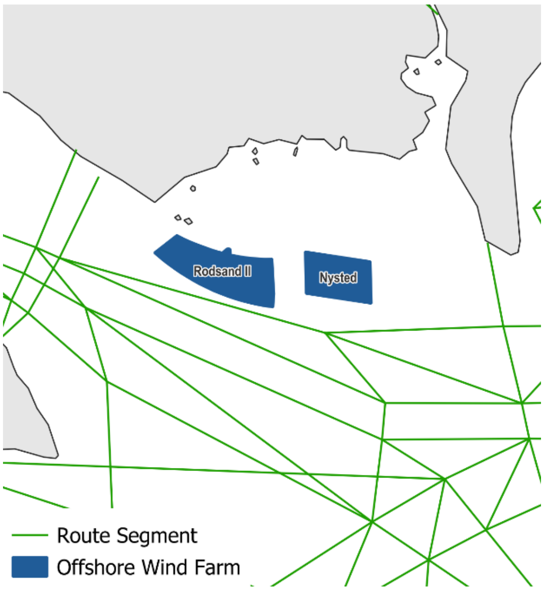

Figure D-2 *Wind farm with route segments*

The cross-track position of passing vessels relative to the route centreline is modelled using a mixture distribution. Under normal operating conditions, vessel deviations are represented by a normal distribution. To account for extreme deviations (e.g. off-nominal navigation), a small fraction is represented by a uniform distribution across the full corridor. In the present assessment, an extreme-case fraction of 2% is applied. The collision frequency is then obtained by combining the traffic frequency on each relevant route segment with the probability that the vessel position falls within the offshore wind farm impact zone.

The spill frequency is closely following the model described in Section D.5.2. This is conservative, since the model in Section D.5.2 applies to stationary ships being hit by a sailing vessel. It is assumed that 10% of the collisions lead to spill of oil. In 30% of the spills it is only bunker oil that is spilled. In 70% of the cases the penetration is such that cargo is spilled. It is assumed that in 26% of the cases the ship is a tank ship. For other ships it is considered that bunker oil is spilled in 3% of the cases.

The amount of bunker oil is assumed to be equally likely to be between 15-300 t or between 300-5,000 t. The spill size distribution for tanker loading is taken to be the same as for spill risk from tanker hit by a dedicated vessels i.e.: 300-5,000 t (25%); 5,000 -15,000 t (50%); 15,000 -50,000 t (20%); 50,000-150,000 t (5%).

The present section focuses on the methodology for assessing the risk of oil spills resulting from ship collisions with offshore wind farms. The resulting spill risk estimates are in a separate deliverable D2.6 *Probability of oil and HNS release* (BRISK II, Prob. of oil release, 2025).

D.5 General modelling

The present chapter summarises two models that have been used throughout this note.

The first model estimates the ship collision frequency for fixed objects and stationary vessels that can be hit by passing merchant vessels.

The second one estimates the spill probability for the case that a ship-ship collision happened.

D.5.1 Ship collision frequency for fixed objects and stationary vessels

The modelling follows closely the approach described in the SED 04 (Larsen, 1993) and is based on the work from Fujii et al. (Fujii, 1984). The frequency of a collision is estimated with following equation.

$$P(C) = N \cdot PC \cdot PG \cdot PE$$

In this equation stands N for the annual number of ships to which the object is exposed to. This includes all ships that pass in the vicinity of the considered structure.

PC is the so-called causation probability. This is the probability that a ship gets aberrant and sails off course.

But a ship sailing off course does not need to collide with the fixed object or stationary vessel. The likelihood that is does is expressed by PG. This is the geometric probability

PE takes into account other effects that influence the exposure of the object. For instance, in cases where the object is not permanent at the location e.g. a ship that is temporarily involved in a bunkering or in a STS operations.

The causation probability is generally taken as $PC = 3 \times 10^{-4}$ per passage. No reduction has been applied for ships with pilots on board or ships that frequently pass the structure and therefore have a better knowledge about the navigational situation in the vicinity of the structure.

The geometric probability has been analysed for each route in the vicinity of the considered structure. The navigation characteristic has been analysed for each route in terms of the location of the mean ship traffic for each direction and in terms of the transversal distribution of the ship traffic. PG has then been evaluated for each route based on these route parameters, the average ship breadth and the object's width, also denoted as collision diameter.

The result of this model is the likelihood of a ship collision of passing merchant vessels with the structure in question. This likelihood is expressed in terms of an annual collision frequency.

D.5.2 Spill probability for stationary vessels struck by passing vessels

Background

In Section 3.3.3, a detailed model for the likelihood of consequences as a result ship-ship collisions between two moving ships is described. Here, a more simple model is described which is found to be appropriate within the context of stationary vessels being struck by passing vessels. The applied model has been established based on observations in (COWI, 2002).

Spills from the striking ship are considered to be negligible because it will collide with the stiff bow and ram into the softer side of the rammed ship.

The potential of oil spills is much larger for the rammed ship. It may be hit such that bunker oil, which often is stored in side tanks, leaks. In case of a tanker that transports hazardous liquids, it is possible that the striking ship has such a high kinetic energy that the double hull structure is destroyed – at least locally – so that an opening is created where the hazardous cargo may flow into the sea.

The model formulated in (COWI, 2002) is based on a chain of subsequent events that have to be fulfilled so that a collision can lead to a spill. The events are:

- The rammed ship is hit at a location where bunker oil or hazardous liquids are stored. The probability of this event is expressed by $P(L)$.
- The indentation z is such that leakage is possible. For bunker oil a single hull structure and for hazardous liquid cargo a double hull structure is considered. The probability of this event is expressed by $P(z>z_{crit})$.
- The rammed tank/cargo compartment is not empty. The probability of this event is expressed by $P(F)$.

The three events are with good reason assumed to be independent. The spill probability in case a collision occurred is then the product of the probabilities of the individual events.

$$P(spill|collision) = P(L)\, P(z>z_{crit})\, P(F)$$

Spill of bunker oil

The probability that the machine room is hit is taken as 9%. In most cases, the hull around the machine room is a single-wall structure and the likelihood that its hull break is estimated to 98%. The tank is not empty, i.e. the likelihood is 100% that there is bunker oil. In case the hull breaks around the machine room then in 35% of the cases there will be a leakage due to a breakage of the tank or due to broken pipes. The spill probability in case of collision is then:

$$P(bunker\ spill|collision) = 0.09 \times 0.98 \times 1.0 \times 0.35 = 0.031.$$

Spill of cargo

It is assumed that in 93% of the cases a cargo compartment is hit. Based on an average double hull wall thickness of 2 m and an average ship width, the likelihood that the indentation is larger than 2 m is assessed to be 16%. Finally, it is assumed that in 60% of the cases the tanks are full. The probability of a spill in case of a collision is therefore:

$$P(cargo\ spill|collision) = 0.93 \times 0.16 \times 0.60 = 0.09.$$

Tanker

The spill frequency for tankers is the sum of the conditional probabilities for bunker spill and cargo spill, i.e. $P(spill|collision) = 0.031+0.09 = 0.12$.

It is argued in (COWI, 2002) that the model comprises some conservatism and therefore, the estimate of the spill frequency is reassessed from 0.12 to 0.10. The spill probability has been compared with observations from collision events in the Danish waters. The found agreement is good and on the safe side.

Applied model for this study

The following simplified model has been applied in the report. It is estimated that hit tankers will produce a spill in 10% of the collisions. In 30% of the spills there will be spill of bunker oil and in 70% of the cases there will be spill of cargo.

Other ships that do not carry hazardous liquids spill in 3% of the cases bunker oil.

Tankers constitute 26% of the total ship traffic. This, the the average probability of a spill in case of collision during bunkering is 4.8%. In case of STS operations, the hit vessel will always be a tanker (probability of spill 10 %, see above).

Co-funded by
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