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BRISK II

Method note

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This document is developed within the BRISK II project to describe the methodology used to carry out the assessments within the project.

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.

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CONTENTS

1 Introduction

The present method note is part of the long-term risk analysis for oil and hazardous and noxious substances (HNS) pollution of the Baltic Sea (BRISK II).

The method note forms the background for the methodological basis of the BRISK II analysis. It comprises the description and documentation of the objectives, assumptions and analytical methods that are applied and that have been agreed upon by the involved experts.

Therefore, the present note is a "living" document, i.e. it is constantly changing as it reflects the methodological adaptations to the actual conditions throughout the project. The note will therefore reflect the appreciation of the methodology at a given time in the project and the note will represent the final documentation when the analysis is finalised.

1.1 Scope

The BRISK II method, which is documented by the note, prepares the grounds for the entire risk analysis. Therefore, it has the following objectives:

› Basic definition of key issues, such as the area to be covered, the division into sub-areas, the substances and scenarios to be dealt with

› Basic principles of how ship traffic, accidents, oil weathering and fate, emergency response and environmental sensitivity are represented in the model

The data and calculation flow of the model is illustrated in Figure 1.1.

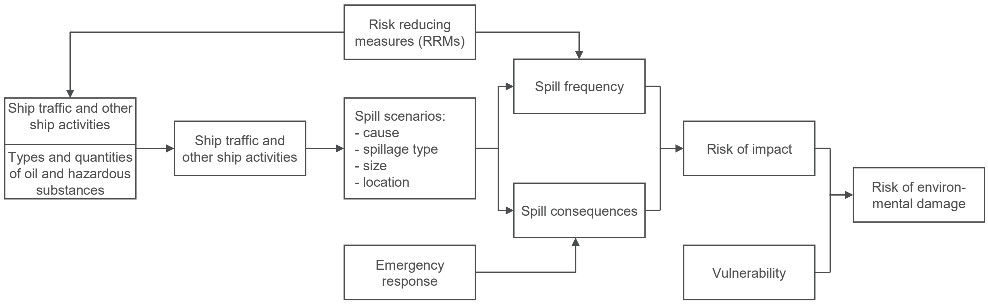

Figure 1.1 Data and calculation flow of the model

Correspondingly, the present method note is divided into the following chapters:

- Chapter 3: Hazard identification and selection of scenarios
- Chapter 4: Ship traffic
- Chapter 5: Transport of oil and hazardous substances in the Baltic Sea
- Chapter 6: Vulnerable areas and classification of vulnerability and damage
- Chapter 7: Frequency and quantity of oil and hazardous substance spillage
- Chapter 8: Spreading and containment of spilt oil and hazardous substances

1.2 General definitions

The following definitions are used:

- *Source:* The facility or operation from which an accidental release of oil may occur (e.g., a pipeline, storage tank, oil tanker, non-tank vessel, offshore installation, etc.).
- *Hazard:* A potential danger which can cause a release of oil (e.g., uncharted rocks, congested waters, poorly maintained equipment).
- *Event:* Refers to an accidental release of oil (a hazard interacts with a source to produce an incident).
- *Frequency:* The statistical number of times an event will occur within a defined sample size over a specific period (e.g., the frequency of an oil spill greater than X tonnes at a location is Y times per Z years).
- *Probability:* Refers to a single event and is expressed as a number between 0 (zero chance) and 1 (certain).
- *Likelihood:* A generic term covering either frequency or probability, depending on the analyses used.

- *Consequence:* The released amount of oil or hazardous substances.
- *Risk:* A measure of both the likelihood and consequence, if a hazard manifests itself (usually expressed by factoring likelihood and consequence together).

1.3 Geographical scope

The geographical scope is limited to the Baltic Sea. In the context of BRISK II, the Baltic Sea is defined as the sea area that is separated from the world ocean by a straight line running almost South-North from Skagen (Denmark) to the border between Sweden and Norway at Strømstad. In addition to the HELCOM defined Baltic Sea area, the BRISK II area also includes the Swedish North Sea coast (figure 4).

Inland waterways adjacent to the Baltic Sea are not part of the scope. Lagoons are regarded as inland waterways, which affects amongst others

- the Curonian Lagoon (Lithuania/Russia)
- the Vistula Lagoon (Russia/Poland)
- the Szczecin Lagoon (Poland/Germany)

The Limfjord (Denmark) is not part of the scope.

The Russian EEZ will only be covered in a generic way based on publicly available data and/or legacy data from BRISK I. Where none of these workarounds is practically meaningful for a given step of the risk analysis, the Russian EEZ will be left out of the analysis.

2 SUMMARY

2.1 Hazard identification and choice of scenarios

Hazard identification and appraisal

In a first step, all conceivable sources to oil spill and spill of hazardous substances into the Baltic Sea are identified. In a next step, they are grouped into three main groups:

- Spill sources included in the risk analysis
- Spill sources not included in the risk analysis, because they are considered out of the scope of the project (e.g. land-based activities, activities in harbours)
- Sources not included in the risk analysis, because the risk is judged to be insignificant (e.g. air traffic)

Hazard identification and appraisal

In a first step, all conceivable sources to oil spill and spill of hazardous substances into the Baltic Sea are identified. In a next step, they are grouped into three main groups:

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Included scenarios

Those scenarios that are included in the risk analysis include:

- Collisions, groundings and fires with spill of cargo in bulk from navigating ships
- Collisions and groundings with spill of bunker fuel from navigating ships
- Spill as a consequence of a collision with a fixed structure (offshore installation, drilling rig, large buoy, wind farm)
- Deliberate or inadvertent discharge/spill of oil from navigating ships
- Spill occurring during STS-operations or during bunkering at sea

2.2 Ship traffic model

Traffic data

Modelling the ship traffic in an appropriate way is one of the corner stones of the risk analysis. Ship traffic data are obtained via AIS (Automatic Identification

System), which consists of messages broadcast by each single vessel, containing information on identity, position, speed over ground, course over ground etc. AIS is compulsory for all vessels with a gross tonnage of 300 tons or more.

AIS data are provided by HELCOM's AIS data base. In addition to traffic data, detailed data on the characteristics of the individual ships are obtained from S&P Sea-web. AIS data are moreover benchmarked against by statistical records maintained by VTS centres and other institutions. This benchmarking process will also allow to compensate from insufficient AIS data coverage from the shadow fleet.

Traffic model and data analysis

Based on an AIS traffic plot, a discrete route net is established. Subsequently, each ship movement is attributed to one of the route legs. On the basis of this analysis, statistics on ship movement geometry, frequency and ship types are established for each single route leg. The analysis is performed twice, once for the ice season and one for the ice-free season due to differing traffic patterns.

In addition to the ship movement analysis, the flow of goods is assessed independently as described in Section 2.3. This information is used to predict the cargo on board the respective ships.

In addition to modelling the present situation, the model equally describes the expected situation in 2036 based on available prognoses on goods transport and fleet development.

2.3 Transport of oil and chemicals in the Baltic Sea

Classification

Oil and hazardous substances are grouped according to their hazard level (yellow/hazardous, red/very hazardous) and behaviour (evaporation, reaction, floating, sub-surface floating, dissolving, sinking). In the model, each group is represented by one characteristic substance. The representative substances are summarised in Table 2.1 and Table 2.2.

Table 2.1 Representative oil types transported as cargo or as bunker fuel

Oil type	Behaviour in case of a spill to the sea
Fuel oil (cargo and bunker fuel)	Floats, possibly sub-surface
Crude oil (cargo)	Floats
Diesel (cargo and bunker fuel)	Floats
Petrol (cargo)	Floats
Low-sulphur oil (cargo and bunker fuel)	*To be investigated under Task 3.5*
Co-processed oil (cargo and bunker fuel)	*To be investigated under Task 3.5*
Vegetable and animal oil (cargo)	Floats

Table 2.2 Representative hazardous chemicals transported as cargo

Hazardous substance	Behaviour in case of a spill to the sea
Benzene	Floats
Toluene	Floats
Acetone cyanohydrine	Soluble
Acrylonitrile	Soluble
Methyl tert-butyl ether	Soluble
Tar	Sinks
Molasses	Sinks

Transport data and analysis

Data on oil and hazardous substances transport are obtained from national databases port data and – where applicable – from VTS centres and similar entities. On this basis, the flow of goods is modelled for each sub-area.

2.4 Vulnerable areas and classification of vulnerability and damage

Method

A number of species and environmental parameters are selected in such a way that they represent what in reasonable terms can understood as a representation of the main environmental values. The abundance of the parameters mapped for each of four seasons.

Environmental parameters

They include parameters such as international protection areas, fouraging areas of migratory birds, breeding areas of fish, areas with aquaculture (e.g. fish farming), fishing grounds, archipelagos, wadden seas, shallow water areas, bathing beaches, cities and rocky shores. Maps of the abundance of each parameter/species are prepared. Foraging areas and breeding areas are only vulnerable on certain seasons therefore maps are developed for each season. Further, the following issues are included in the vulnerability assessment: Risk for environmental damage during clean-up operation and regeneration time of affected organisms and the affected areas.

Vulnerability weight

The parameters are connected to a relative environmental weight for each season. The weight represents the relative variation of the environmental importance of the specific parameter or species in each specific season.

Vulnerability maps

The selection of parameters and species and the respective weights are determined in consensus among the involved experts and represented open and transparently. This way the analysis can be followed by external experts and, if necessary, it can be revised based on a changed prioritisation. The sum of the weighted environmental parameters represents the accumulated environmental vulnerability to impacts of oil spill or hazardous chemicals for each season. Hence vulnerability maps are prepared for each impact and each season.

Environmental damage

Environmental damage is defined as the product between the impact on a specific area (e.g. as kg oil per km^2 water surface at a given probability) and the vulnerability of the area. The calculated value as such is a hybrid number since it contains the subjective but transparent and systematically developed vulnerability. The damage shall be looked upon as an index for relative and comparative analysis (change of traffic pattern, enhanced response action, etc.).

2.5 Frequency and quantity of oil chemicals spillage

The spill frequency model assesses the expected accident frequency for the scenarios mentioned in section 2.1 and the expected amount of oil and hazardous substances released due to these scenarios.

Accident frequency

Depending on the available methods and the relative importance of a scenario, one of the following two approaches are used:

- Fujii's model, which models the accident frequency based on number of passages, geometrical accident probability and causation probability (i.e. the probability that a ship on collision course with another ship or object does not undertake successful evasive action)
- Statistical approaches, which describe the accident frequency per sea mile based on available statistics

Fujii's model is used for ship-ship collisions as well as collisions with fixed objects (oil platforms, wind farms etc.). In the case of grounding and fire, accident statistics are used.

Accident consequences

In the case of ship-ship collisions – which has proved to be the most important scenario in terms of spillage during earlier analyses – a detailed simulation model is used. It estimates the probability of different spill sizes for a vast number of ship-ship combinations.

As for the other scenarios, the expected spill size in case of an accident is obtained from various studies, statistics and estimates.

Deliberate and inadvertent spills

Deliberate and inadvertent spills comprise all spill events that are not the consequence of an actual accident. They are modelled as a frequency per sea mile based on relevant statistics.

2.6 Spreading and containment of spilt oil and hazardous substances

Introduction

The modelling of the transport and dispersion of oil and chemicals within the Baltic Sea area is based on numerical modelling that simulates the dominant processes, including the effects of degradation (weathering and fate). The effect of the emergency response to the spills is likewise modelled.

Hence, the results can form the basis for strategic decisions concerning the future development of the emergency response while considering changed and increased ship traffic on one hand, and the effect of future risk reduction on the other hand.

Separate modelling is carried out for each of the six seasons, i.e. winter (no ice), winter (ice), spring (ice), spring (no ice), summer, autumn. The reason is that the vulnerability varies throughout the year and because the presence of ice significantly changes the dispersion pattern of oil and chemicals.

Oil and floating chemicals

The modelling includes a description of the spreading of the oil on the water surface, the drift by current and wind (with or without ice cover), as well as the decay of the oil. For light oil types the decay is simplified to describe only the evaporation while for heavy oils the decay is simplified to describe emulsification and natural removal from the surface. As a result the following is found:

- The amount of pollution and the duration oil in each calculation cell in the open sea area
- The total amount of oil hitting the shoreline

Detailed models are applied for simulation of a few selected scenarios. From these results a simple model is established, which can calculate a large number of scenarios in a short time.

The drift, spreading and decay of oil is first calculated for selected key scenarios with complex and detailed models (MIKE3, SeaTrackWeb, Ice models, analytical models) for a number of oil types, wind- and temperature conditions, spill locations and quantities etc.

The decay, including emulsification, is modelled as a change in the mass of the spill as a function of time. Submerged oil and its reduced decay during submerging also is included.

Ice

Ice cover is modelled as a condition which modifies the above description of drift and decay. The ice cover is modelled as complete ice cover, broken ice or no ice. In case of complete ice cover it is assumed that the oil spill remains at the same position with its characteristic diameter and thickness, and that no decay occurs. In case of broken ice it is assumed that the entire oil spill adheres to the ice and that drifting hereof follows the drift velocity and direction of ice.

Emergency response

The emergence response applies a wide range of different equipment including ships, barges, pumps, skimmers, booms, sweepers and barriers as well as different hardware such as radar etc. For oil spills in broken ice or in complete ice-covered waters it is assumed that special equipment is used. To describe the effect of the emergency response on the oil spill in a practical manner in the model complex, the response methods are reduced to include only the capacity of pumps and skimmers, as well as the equipment applied to convey the spill to the skimmers, e.g. booms attached to tow boats. The effect of the emergency response is modelled as a reduction of the amount of oil in the circular oil slick. The diameter hereof is unchanged, while the thickness reduces.

In addition, the modelling contains a number of conditions which may influence the effectiveness of the emergency response, such as visibility, darkness, limiting significant wave height etc. A reduced effectiveness is assumed for compounds labelled with Fire Hazard Class 'red' and Health Hazard Class 'red'.

The modelling provides an opportunity for evaluating the effect on the environment from changes in the emergency response. Different response strategies can be defined for the various waters of the Baltic Sea

Soluble chemicals

The impact from spills of soluble chemicals is calculated on basis of the generalised descriptions of dilution through transport and dispersion of miscible fluids in the ocean. Decay of the soluble chemicals is not included.

The dilution calculations are carried out by calculating the distance between the emission point and the location where the concentration is less than the official threshold values for eco-toxicological impact on marine organisms. Such threshold values are determined by experiments using various types of chemicals.

The applied model is called the PEC/PNEC model, which is an abbreviation of Predicted Effect Concentration / Predicted No Effect Concentration. The model calculates the distance where the calculated concentration is equal to the threshold value, below which there is no detectable effect on marine organisms.

Sinking chemicals

The effect on the environment of chemicals that sink are not included in the present since no incidence with severe damage involving sinking chemicals is reported.

3 Hazard identification and selection of scenarios

3.1 Introduction

The purpose of the present chapter is to serve as a paradigm for the hazard identification and scenario selection for the entire BRISK area as identified in BRISK I, i.e. the Baltic Sea area as defined by HELCOM and the Swedish part of the North Sea coast (see figureFigure 4.9.

The risk analysis identifies a number of scenarios describing incidents with spills of oil and chemicals which may cause harm to the marine environment. These scenarios are selected to give an adequate and covering description of the risk imposed on the marine environment due to such spills, i.e. not all possible scenarios are modelled.

A risk analysis shall consider the likelihood as well as the consequences of oil and chemical pollution in the Baltic Sea as basis for the next stages in the project. The aim of the analysis is to provide a common basis for the future development of the emergency preparedness with respect to combat of oil and hazardous substance spills in the Baltic Sea.

The first part of the risk analysis is a systematic identification of sources of unwanted spills of oil and chemicals to the marine environment. For each source of spill the overall risk to the marine environment is assessed and the sources are grouped as follows:

- Sources included in the risk analysis. Scenarios modelling the risk are set up.
- Sources not included in the risk analysis, because combat of the corresponding spills are considered to be outside the scope of the project. This applies essentially to land-based activities and activities inside harbours and lagoons (compare Section 1.3).
- Sources not included in the risk analysis, because the risk is judged to be insignificant.

The risk analysis does not consider continuous and permitted releases even if such may cause harm to the marine environment. This is because the emergency preparedness is not required to combat the effects of such spills. Examples would be a continuous release of chemicals and other harmful substances in waste water from on-shore sewer systems.

Sabotage, terror and acts of war are not covered by the risk analysis. Sabotage and terror events are difficult to assess in a risk analysis as the likelihood is impossible to set. An emergency preparedness able to combat likely events threatening the marine environment would in most cases also be able to act effectively against acts of sabotage and terror. Acts of war shall not be the basis for the design and sizing of the emergency preparedness.

Identification and assessment of sources are reported in Section 3.2.

For the sources to be included in the risk analysis scenarios for spills of oil and chemicals are set up. The scenarios include the elapse of the incident up until the spill takes place. For spills of oil and chemicals with potential of damaging the marine environment a span of consequences is modelled. These are, however, not described here, but primarily in Chapter 8.

The scenarios are described in Section 3.3.

3.2 Identification of sources of spill to be modelled

The risk analysis models a number of scenarios for spills of oil and chemicals in the Baltic Sea. In this section all possible types of spill are identified and it is assessed if the risk due to these spills is large enough to have an impact on the planned subregional emergency preparedness. Only spills that are large, harmful and frequent enough are modelled.

3.2.1 Global hazard identification

The following main sources of spill to the sea able to cause damage to the marine environment have been identified:

- Ships
- Land based activities (outside the scope of the risk analysis)
- Offshore oil and gas extraction (partly outside the scope of the risk analysis)
- Other offshore activities
- Air traffic, satellites etc.
- Subsea dumping sites
- Nature (e.g. an oil reservoir not occurring due to human activities for extraction of oil).

These main sources of spill are considered in the following sections.

3.2.2 Ships – overview

The main topic of the risk analysis is pollution of the marine environment caused by ships.

Considering the large variety of ships and ship activities the following subdivision has been applied:

1 Cause of spill to the sea

2 Type of ship

3 Size of ship

4 The ship's activity at the time of spill to the sea.

3.2.3 Cause of spills at sea

Distinction is made between the following spill causes:

- Accidents at sea. Accidents where the ship is damaged e.g. collisions and groundings leading to spill of oil or chemicals to the marine environment.
- Deliberate spills. Actions including illegal discharge of large amounts of polluting material to gain a benefit. The action is, however, not performed to cause deliberate damage to the marine environment. Typical actions of this nature would be flushing of tanks and emptying of waste oil tanks.
- Inadvertent spills. Such spills include spills due to faulty operation etc. without causing damage to the ship itself. Such spills will typically be minor spills e.g. a fault in the cooling water system causing large amounts of lubricants to be spilled to the sea.
- Goods damage. Spills due to mechanical damage to containers or their fastening without damage to the ship. Whole containers or their contents are lost overboard.

Accidents at sea

The risk analysis focuses on accidents at sea. These accidents may give rise to large spills having a huge impact on the marine environment. These large spills define the design loads for the emergency preparedness and disaster response. The sections below on ship type and ship activity are arranged mainly focusing on accidents at sea. Scenarios modelling accidents at sea causing spill of oil or chemicals are set up.

Deliberate and inadvertent spills

Both deliberate and inadvertent *oil* spills are expected to be considerably smaller than spills after an accident. Thus such spills are not likely to cause extensive damage to the marine environment. However, these spills are relatively frequent and because of this, they must be included in the risk analysis. The contribution to the total risk to the marine environment due to deliberate and inadvertent discharge/spills of oil are modelled based on statistical experience of the elapse of this type of spill (see Chapter 7).

In an earlier analysis of oil spill in Danish waters, no deliberate or inadvertent discharge/spills of chemicals have been registered (Oil spill DK, 2007) and it is deemed not to be a relevant scenario in quantitative terms in the Baltic Sea as a whole. Substances to be released may e.g. be ammonia; however, chemicals transported in bulk are typically not the most harmful to the environment (compare Chapter 5). It is found that the risk due to deliberate and inadvertent spills of chemicals is small and modelling of these is not required.

Damage to cargo, no damage to ship

Damage to or loss of cargo not caused by a sea accident is only likely to occur from container ships and general cargo ships carrying deck cargo. A typical scenario would include that the deck load is damaged or washed overboard in a storm.

Loss of drums or containers or damage to these in Danish waters causing spills is a rare event. In the case of Denmark, only one such incident has been recorded back in the 1980ies (Oil spill DK, 2007). This situation is regarded as representative for the entire Baltic Sea.

Considering that the amount of oil products in a single container or a drum is likely to be small it is found that the risk of oil pollution of the Baltic Sea due to loss of or damage to containers or drums is negligible compared to other modes of spill. Thus this contribution to the risk is not modelled.

Likewise, the same may be concluded considering containers and drums holding chemicals – scenarios describing large spills of chemicals from bulk carriers are included among the sea accidents – these large spills are considered the potentially most harmful to the marine environment (compare Chapter 5).

3.2.4 Type of ship

Analysing accidents at sea the following types of potentially harmful ship are considered:

- Ships with a cargo of oil or chemicals harmful to the environment if spilled
- Ships not transporting oil or chemicals, but carrying oil or harmful chemicals for use on the ship

Ships with a cargo of oil or chemicals

The harmful cargo may be in bulk or in containers packed as dangerous goods. Packed dangerous goods also include loads on road tankers or in bulk in lorries on board ferries. Thus the following types exist:

- Ships carrying a cargo of oil in bulk:
  - Tank vessels (including ships able to carry both oil and other chemicals in their tanks). This is the main topic for the risk analysis. Scenarios for accidents at sea are set up in Section 3.3.2

  - Spills due to tank flushing will be handled by a statistical method as described in Sections 3.2.3 and 3.3.7

- Ships carrying oil products packaged as dangerous goods:

  - Ferries (Ro-Ro) transporting railway carriages and road tankers with oil products. Due to the small amounts in each container or tank the risk to the marine environment is small and modelling of this type of spill during an accident at sea is not required.

  - Container ships. In principle oil products may be transported by container ships packaged in smaller containers. This is, however, considered only to occur rarely as the amount of products in the individual container would be limited. As above the risk is small and spills of this type during an accident at sea is not modelled.

  - Ships carrying general cargo. Same as indicated for container ships

  - Offshore supply vessels. Same as indicated for container ships.

- Ships carrying chemicals in bulk:

  - Tankers and bulk carriers (including ships able to carry various types of product in their tanks). Spills of chemicals from these ships due to accidents at sea is modelled, Section 3.3.2.

- Ships carrying chemicals as packaged goods:

  - Ferries (Ro-Ro) transferring railway cars or trucks carrying dangerous goods

  - Container ships

  - General cargo ships

  - Offshore supply vessels.

  Because the amounts of chemicals transported in these vessels are by far smaller than the amounts transported in bulk and because the spill scenarios considered include spills of chemicals transported in bulk, which are among the most hazardous considering harm to the environment (Chapter 5), the risk due to spills of chemicals from ships carrying packaged goods is not modelled.

- Ships carrying radioactive substances and other extremely dangerous substances

Radioactive substances and other extremely dangerous substances (e.g. dioxine) are not part of the analysis, because

- These substances are packaged after special principles, which means that an accident at sea will typically not cause any spill, because the container remains intact.
- It is very difficult to obtain reliable data on the transport of such substances. We can only presume that the quantities are small and that transports of this type are rare.

Ships without a cargo of oil or chemicals

In principle all types of ship will carry oils and chemicals for their own use. However, the amounts will be limited.

The following compounds have been identified as potentially harmful:

- Bunker fuel, i.e. oil required for the propulsion and operation of the ship. Fuel for the ship's engine including the main engines and emergency generators etc.
- Various types of oil e.g. lubricant oils and hydraulic oils.
- Chemicals. Such may be:
  - Chemicals required for waste treatment, cooling plants, cleaning, rat control etc.
  - Paint, some include chemicals to prevent fouling.

  The amounts of these chemicals are likely to be small. The most harmful are assessed to be chemicals for cooling plants (ammonia, HFC, freon at older ships) and paint. Chemicals for cooling plants are stored in smaller pressure bottles. Paint is kept in pots and the amount stored would at most be some 30 pots each containing 20 litres (Petersen, 2006; Høyer, 2006).

The risk due to spills from ships only carrying oil and chemicals for their own use are analysed in the following way:

- Scenarios describing spills of bunker fuel due to accidents at sea are set up, Section 3.3.3. In these scenarios also spills from tanks holding lubricants are included in case these tanks are more exposed to damage than the fuel tanks (during grounding).
- Deliberate and inadvertent discharge/spills of all types of oil are treated using statistical methods as described in Sections 3.2.3 and 3.3.7.
- Because the amounts of chemicals for the ships own use are rather limited, the containers are small and because the likelihood of spill is small, modelling

of these spills due to accidents at sea is not required. Further as indicated in Section 3.2.3 there is no need to analyse deliberate and inadvertent discharge/spills of chemicals.

3.2.5 Size of ship

The risk analysis does not consider ships of a size below 300 GT. The reason for this is partly that these ships are so small that they do not carry a cargo of oil or chemicals and they may only cause relatively little harm due to spills of bunker fuel, partly that these ships have no obligation to transmit AIS-signals which are the main source for mapping the ship traffic (compare Chapter 4).

In 'Oil spill DK' (2007) the spills registered from ships smaller than 300 GT were considered, and it was found, that they are of insignificant importance.

3.2.6 Vessel activity at the time of spill

Distinction is made between the following activities:

- Navigation at sea (outside harbours)
- Transfer of oil at sea
- Transfer of chemicals at sea
- Special activities at sea
- Activities in harbours

Navigation at sea

Scenarios are set up describing spills of oil and chemicals from ships due to accidents at sea, see Sections 3.3.2 and 3.3.3. Deliberate and inadvertent discharge/spills are treated statistically, see Section 3.3.7.

Transfer of oil at sea

Transfer of oil at sea may be:

- Transfer of a cargo from ship to ship (STS). Individual scenarios for this activity covering both accidents at sea and inadvertent spills (errors during operation etc.) are set up, see Section 3.3.8.
- Transfer of oil cargo from offshore production facility to ship. This does not take place in the BRISK II area and is consequently not modelled.
- Transfer of oil cargo between a ship and a buoy with a pipe connection to shore.
- Transfer of bunker fuel from bunker ship to another ship passing through the Baltic Sea. Individual scenarios are set up covering both accidents at sea and

inadvertent spills (errors during operation etc.), see Section 3.3.9. The scenarios cover all types of transfer of oil to be used on the ship, see Section 3.2.4.

Transfer of chemicals at sea

The following has been identified:

- Transfer between supply vessels and offshore installations. In the case of Denmark, spills during these operations are not the responsibility of the national coast protection authority (Ministry of Defence), see Section 3.2.8. Consequently, the risk of spills during this activity was not modelled in 'Oil spill DK' (2007). The same approach was adopted for BRISK I (BRISK I, 2011).

Special activities at sea

Special activities at sea include:

- Cargo ships:
  - Transfer of provisions, persons etc.
  - Anchoring while waiting for a weather change
  - Hove-to while waiting for a weather change
  - Anchoring while waiting for a new task.
- Vessels performing special activities e.g.:
  - Diving ship supporting divers
  - Cable-laying vessel at work
  - Dredging, deepening and extraction of materials at sea.
- Fishing ships at work

For these activities no scenarios are set up. However, accidents at sea can occur during these activities (and have done so in case of the Danish waters) and they are included in the statistical basis for modelling ships navigating at sea.

Special activities in general have a rather small frequency compared to ship traffic in general. Possibly fishing may not be small, however, only very few fishing vessels are of a size large enough to contribute significantly to the hazard of oil or chemical spills causing harm to the marine environment: Only a few of the signals from AIS are from fishing vessels. A list prepared by Statistics Denmark indicating the size distribution of Danish fishing vessels (Statistics DK, 2006) shows that among around 750 fishing vessels larger than 20 GT about 14% are larger than 300 GT and about 7% are larger than 500 GT.

Activities in harbours

Activities in harbours are outside the scope of the risk analysis.

Mooring systems do exist at locations not protected by outer jetties. These systems without outer jetties are equally considered as harbours.

3.2.7 Land-based activities

Spills of oil and chemicals from shore-based activities may occur after incidents at the plants and during transportation on road or rail. Further spill in connection with agricultural activities may occur.

Incidents at plants

During an incident on a shore-based plant spills of oil and chemicals may reach the marine environment in several ways:

- By sewer systems possibly taking the spill to an area at some distance from shore
- By streams to the sea
- Directly to the sea in case the plant is located close to the sea.

Such incidents are outside the scope of the risk analysis.

Spills during transport

In case of spill events during transport oil and chemicals may reach the marine environment:

- By sewer systems
- By streams to the sea
- Directly to the sea from a road along the coast
- Directly to the sea from a bridge across an area of sea.

Such incidents are outside the scope of the risk analysis.

Spills from agricultural incidents

Spills from agricultural incidents would be able to reach the marine environment by the following routes:

- By sewer systems possibly taking the spill to an area at some distance from shore
- By streams to the sea
- Directly to the sea in case the activity is located close to the sea.

Such incidents are outside the scope of the risk analysis.

3.2.8 Offshore oil and gas activities

Spills from oil and gas activities may occur in the following ways:

- Release directly from the reservoir (blowout) during prospecting and exploration. During these activities a drilling rig may be working at a location not housing a permanent offshore facility
- Release directly from the reservoir (blowout) from a permanent offshore facility. This may occur during drilling of a production well, drilling of wells for injection of water or gas, during production or during work-over
- Spills from equipment on a permanent platform
- Spills from pipelines for transport of oil or gas
- Spills from the reservoir (blowout) from wells that are closed
- Spills during transfer of cargo between supply vessels and platforms or drilling rigs
- Spills from ships that collide with platforms or drilling rigs
- Spills from supply vessels that calling at platforms or drilling rigs

In accordance with the assumptions in the earlier Danish analysis, fixed platforms and drilling rigs are not considered to be within the scope of the analysis.

During the BRISK I project it was decided that the hazards due to the following incidents *are to be included* in the scenarios. The same approach is applied in BRISK II:

- Spill from platforms and drilling rigs (including equipment and pipelines) due to vessel impact. Both dedicated and passing vessels are considered.
- Spill from platforms and drilling rigs (including equipment and pipelines) independent of any vessel activities.
- Spill from ships after collision with a platform or a drilling rig. Both dedicated and passing vessels are considered. The two types of ship are, however, modelled separately using different models, Section 3.3.4 and Chapter 7.
- General spills from ships calling at platforms and drilling rigs. The risk of spill from this type of traffic is modelled as part of the general risk of spill from all navigating ships, Section 3.3.2 and 3.3.3.

The risk of releases from closed wells and test drills was also investigated in ‘Oil spill DK’ (2007), where it was found that modelling of this risk is not required. This is assumed to apply equally to the Baltic Sea as a whole.

3.2.9 Other offshore activities

Other offshore activities e.g.:

- In accordance with the assumptions in the earlier Danish analysis, subsea oil pipelines are not considered to be within the scope of the analysis. This applies equally to potential subsea chemical pipelines. Releases from subsea gas pipelines are not considered a primary environmental threat and cannot be combated either.

- Construction and operation of sea-based wind turbines.

  Some incidents at this type of installation may result in spills causing pollution of the marine environment. However, the potential of harm is judged to be small and thus this type of spill is not investigated further. Reference is made to 'Oil spill DK' (2007).

  Spills from ships calling at the installations are treated within the general model of spills from navigating ships, Section 3.3.2 and 3.3.3. The risk due to this type of navigation is not specifically modelled.

  Spills from ships colliding with the installations are considered in 'Oil spill DK' (2007). There, it was found that the risk is in fact negligibly small compared to other spill sources and was consequently not modelled. Nevertheless, it has been decided to be model this risk in the present project in accordance with BRISK I (BRISK I, 2011) due to a number of existing and planned offshore wind farm projects (see Section 7.7.2).

- Construction and operation of bridges and tunnels above and below the sea.

  Incidents at these structures may cause spills polluting the marine environment. The risk of pollution is judged to be small and the subject is not considered further.

  Spills from vessels participating in the construction or operation of such structures are included in the general modelling of navigating ships, Section 3.3.2 and 3.3.3. Thus the risk of this type of activity is not modelled in detail.

  Spills from ships after a collision with a bridge or a tunnel were considered in 'Oil spill DK' (2007), where it is found that the risk is so small, that it needs not be modelled. When considering that Denmark has several such structures crossing some of the most heavily used sailing corridors in the entire Baltic (bridge and tunnel across the Great Belt, bridge and tunnel across The Sound and several other large bridges across minor straits), it is reasonable to assume that this risk does not provide a relevant contribution in other parts of the Baltic either.

- Operation of large buoys.

In some parts of the Baltic Sea (e.g. in the waters surrounding Åland), very large buoys are in use and cases of ship-buoy collisions have been reported. Although the risk of pollution can be expected to be rather small compared to other potential spill causes, it has been decided to model this risk (see Section 7.7.1).

3.2.10 Aircraft, satellites etc.

The Baltic Sea may be polluted by flying objects falling off the sky and from spills when the objects are damaged at the impact.

Objects falling from the sky

Aeroplanes may spill jet fuel in amounts up to what the largest planes may hold. Further air freighters may drop containers holding dangerous goods.

Jet fuel is a rather light oil product with a density of about 0.81 (Irving, 2006). In case of a spill after a crash the jet fuel will evaporate within short. The maximum amount spilled would be small. A Boeing 747-400 (jumbo jet) has a tank capacity of 217 m^3 (Boeing, 2006) i.e. some 180 tonnes. In the case of Denmark – which is expected to be more exposed to airborne sea pollution than other HELCOM nations, considering that it has one of the smallest EEZs and hosts one of the most heavily frequent airport hubs in the region at the same time – it is easy to show that the likelihood of a plane crash in the country’s EEZ is considerably smaller than the likelihood of spills of oil and chemicals due to accidents at sea (Oil spill DK, 2007): The frequency of crash of a large airplane in Danish waters may be estimated at 0.03 per year based on 189.000 flying hours in Danish airspace during 2005 (CAA-DK, 2006) and a probability of fatal accidents per flying hour for route and charter flight of 1.6×10^{-7} in the USA during 2005 (NTSB, 2006). For the smaller airplanes the likelihood is larger, but these planes carry very small amounts of fuel.

The risk of pollution from other types of flying objects falling of the sky including satellites, air ships and air balloons is without further judged to be negligible.

In conclusion modelling of the risk to the marine environment due to flying objects falling off the sky is not required as the risk is insignificant.

Spills from flying objects

During emergencies aeroplanes may dump fuel in the air before landing. The fuel will be finely dispersed in air (Puckgaard, 2006) and the fuel will not reach the sea in a way observed as pollution of the marine environment. It is found that modelling of the risk to the marine environment from this type of spill is not required.

3.2.11 Subsea dumping sites

In the Baltic, there are a number of subsea dumping sites for mines, containers holding mustard gas etc. from World War II (e.g. off Bornholm). Releases from these sites e.g. due to fishing activities may harm the environment.

The nature of these hazards and the corresponding emergency response is quite different from the preparedness to combat spills of oil and chemicals in general.

Thus, the risk of releases from subsea dumping sites is not covered by the present study.

3.2.12 Nature

This source of pollution is considered for completeness.

A possible scenario would be:

- Release from an oil reservoir not occurring due to human activities for extraction of oil (these releases/spills are covered by the activities described in Section 3.2.8). Such a scenario is not likely to occur in the Baltic Sea. However, it is noted that releases from an abandoned oil well may be considered as a "release from nature", if it is not possible to point out an owner or operator of the well.

It is found that it is not required to model such releases.

Additional sources of pollution relevant for the emergency preparedness in the Baltic Sea have not been identified.

3.3 Scenarios

3.3.1 General

Based on the identification in Section 3.2 scenarios for the following incidents are set up:

- Accidents at sea and spill of cargo in bulk from navigating ships, see Section 3.3.2
- Accidents at sea and spill of bunker fuel from navigating ships, see Section 3.3.3
- Spill as a consequence of a collision with a fixed structure:
  - Collision with an offshore installation or drilling rig, see Section 3.3.4
  - Collision with a large buoy, see Section 3.3.5
  - Collision with a wind farm, see Section 3.3.6
- Deliberate or inadvertent discharge/spill of oil from navigating ships, see Section 3.3.7
- Spill occurring during STS-operations, see Section 3.3.8

› Spill during bunkering at sea, see Section 3.3.9

3.3.2 Accidents at sea and spill of cargo from navigating ships

The accident

The following types of accident are considered:

1 Grounding

2 Collision with other ship

3 Collision with fixed structure. The model differentiates between:

   3.1 Collision with offshore installation. This is modelled separately as described in Section 3.3.1.

   3.2 Collision with all other types of fixed structure. This was described in 'Oil spill DK' (2007), where it was found that modelling of this is not required as the risk is small.

4 Fire and explosion

5 Other types of sea accident leading to a loss of the ship as this may result in spills

Rare or very complex scenarios are not modelled. Such may e.g. be:

- Collision with a sunken ship. An example is several collisions with the Norwegian car carrier Tricolor that sunk in the English Channel on 14 December 2002 (Scotsman, 2003).

- Ship-ice collision leading to hull penetration and subsequent cargo or bunker spill. An analysis of 61 incidents in which ships were damaged by sea ice in the Baltic Sea in 1984-1987 did not reveal a single case of leakage (Kujala, 1991). Although this risk cannot be principally excluded, it is deemed negligibly small on the basis of this result.

  (Other sea ice-related effects such as a modification of ship-ship collision and grounding frequencies are however included in the respective models.)

- Aeroplane crashing and hitting a ship. No accidents of this type are found.

These rare and complex scenarios will only contribute insignificantly to the overall risk of pollution due to oil and chemical spills in the Baltic Sea. In case such events have occurred in the Baltic Sea they will have been included in the data base of sea accidents and consequently they will be part of the basis for the risk analysis.

Ship and material spilled

For all of the accidents described above the following combinations of ship type and type of spill are considered:

- Tank vessel and spill of oil cargo
- Tank vessel and spill of chemicals either as gas or liquid
- Bulk carrier and spill of solid chemicals

Scenarios with spills of liquid (and gaseous) chemicals from tank vessels and scenarios with spills of solids are combined and modelled as spills of liquid (and gaseous) chemicals from tank vessels. The reason for this is on the basis of information from the Danish waters:

- Only a fraction of the environmental harmful chemicals transported in bulk will consist of solid chemicals
- It is judged to be on the safer side to model a spill of a solid as a liquid.
- Most environmentally harmful chemicals transported in bulk are only chemicals that will dissolve, react or sink and the modelling of the consequences of spills would be the same irrespective of if the chemical initially was a liquid or a solid.

1 Tank vessel and spill of oil cargo

The types of oil indicated below are modelled (compare Chapter 5). For each type density, solubility in water as well as possible "red" classifications considering fire hazard, health hazard and environmental hazard are indicated:

- Petrol, floats, “red” fire hazard, “red” health hazard
- Diesel, floats
- Crude oil, floats
- Fuel oil is modelled by IFO 380, may float just below the surface and a probability is indicated
- Co-processed oils, defined as oil where a portion of the crude oil is replaced with renewable or recycled raw materials
- Low-sulphur oils, defined as oil with 0.5 % or less sulphur content

The magnitude of spill:

- 3 t (1 - 10 t)
- 30 t (10 - 100 t)
- 300 t (100 - 1.000 t)

- 3.000 t (1.000 - 10.000 t)
- 30.000 t (> 10.000 t)

Spills less than 1 tonne are not considered as such small spills are judged to occur very rarely.

The spill is assumed to occur instantaneously.

Time of spill compared to the time of accident:

- Immediately as the accident occurs
- Late compared to the time of accident.

It may be considered to model a delayed time of spill for a situation when a ship is grounded. In that case a spill may occur after some time as the ship may first be damaged later. However, it was found that groundings only give a small contribution to the risk compared to collisions, see 'Oil spill DK' (2007). Thus, to simplify the calculations this effect was omitted both in 'Oil spill DK' (2007) and BRISK I (BRISK I, 2011).

2 Tank vessel or bulk carrier and spill of chemicals

Chemicals are classified in accordance with their physical properties when they have been spilled. Further ”red“ classifications are indicated in accordance with Chapter 5. It is noted that chemicals reacting are not considered separately. In that case the products of the reaction are considered.

- Gaseous chemicals or chemicals evaporating after spill: These chemicals are not harmful to the marine environment (except that birds may be killed flying into a toxic cloud of gas, e.g. ammonia or be caught in a cloud of gas on fire e.g. propane). Based on this, scenarios with spill of gaseous chemicals are not considered individually. An overall estimate of the risk due to such spills is, however, made for each area of the sea.

- Chemicals floating on and not mixing with the water:
  - Benzene, C_6H_6, “red” fire and “red” health hazard
  - Toluene, $C_6H_5CH_3$, “red” fire hazard

  No chemicals with “red” environmental hazard are identified, see Chapter 5.

- Chemicals not mixing with water and floating just below the surface. No such chemicals have been identified transported in bulk through the Danish waters.

- Chemicals soluble in water or reacting with and dissolving in water (here classification indicating "red" fire hazard and "red" health hazard would not be relevant, see Chapter 5). The following chemicals are considered as representative of this group:

- Acetone cyanohydrine, C_4H_7NO, “red” environmental hazard, MARPOL class XA
- Acrylonitrile, CH_2CHCN, “red” environmental hazard, MARPOL class XB
- MTBE, methyl-*tert*-butyl ether, $C_5H_{12}O$.

- Chemical substances not mixing with but sinking in sea water (here a classification indicating a “red” fire or health hazard is not relevant, see Chapter 5):
  - Tar, “red” environmental hazard
  - Molasses.

The magnitude of the spill:

- 3 t (1 - 10 t)
- 30 t (10 - 100 t)
- 300 t (100 - 1.000 t)
- 3.000 t (1.000 - 10.000 t)
- 30.000 tons (> 10.000 tons)

Spills below 1 t are not considered as spills this small due to damaged tanks would be very rare.

The spill is assumed to occur instantaneously.

Time of spill compared to the time of accident:

- Immediately as the accident occurs
- Late compared to the time of accident.

As indicated for the tank vessels carrying oil only immediate spills are considered.

3 Container ships, general cargo ships, ferries (Ro-Ro), offshore supply vessels, nuclear transports and spills of oil and chemicals transported in containers

The risk to the marine environment due to accidents at sea leading to spills of oil or chemicals transported as packaged dangerous goods is not modelled as the contribution to the overall risk for the marine environment is small, see Section 3.2.4.

3.3.3 Accidents at sea and spill of bunker fuel

The accident

The same types of accident as described in Section 3.3.2 would also be relevant here.

Ship and material

All types of ship defined in Section 3.2.4 are relevant.

The following types of bunker fuel are considered, see Chapter 5:

- Diesel, floats
- IFO 380, may float just below the surface and a probability is indicated.
- Co-processed oils (see also Section 3.3.2)
- Low-sulphur oils: (see also Section 3.3.2)
- Methanol: As a noxious liquid substance presenting a hazard to marine resources and human life cf. MARPOL category Y (IMO, 1987b)), it is in the BRISK II model grouped as soluble substance not falling under MARPOL category X. As such, it is represented by methyl-tert-butyl ether, see Section 3.3.2

Magnitude of spill:

- 3 t (1 - 10 t)
- 30 t (10 - 100 t)
- 300 t (100 - 1.000 t)
- 3.000 t (1.000 - 10.000 t).

Spills less than 1 t are not considered as such small spills after damage to bunker tanks are judged to occur very rarely.

The spill is assumed to occur instantaneously.

Time of spill compared to the time of accident:

- Immediately as the accident occurs
- Late compared to the time of accident.

This issue is handled in the same manner as indicated for tank vessels and spill of oil cargo see Section 3.3.2, i.e. only immediate spills are considered for accidents at sea.

3.3.4 Collision with offshore platforms and drilling rigs

Three sub-scenarios are considered:

- Spill from platforms and drilling rigs (including equipment and pipelines) due to vessel impact. Both dedicated and passing vessels are considered.

- Spill from platforms and drilling rigs (including equipment and pipelines) independent of any vessel activities.

- Spill from ships after collision with a platform or a drilling rig. Both dedicated and passing vessels are considered. The two types of ship are, however, modelled separately using different models.

In principle, the vessel-related scenarios can involve powered as well as drifting vessels. However, the probability of damages to the ship that are sufficiently severe to cause leakage is very small in case of a drifting collision. Therefore, only powered collisions are considered.

In 'Oil spill DK' (2007) it was shown that spills from the vessels themselves only gives a small contribution to the overall risk. Spills from the vessels may consequently be modelled in a simplified manner.

3.3.5 Collision with large buoys

Collisions of passing ships with large buoys resemble collisions with other fixed objects such as platforms and will be modelled accordingly. In terms of collision consequences (leakage), the situation resembles ship-ship collisions, with the involved ship being in the role of the hitting ship and the buoy being in the role of the hit ship. In most cases, the hitting ship suffers only small damages. However, the situation can be different, if a small ship hits a very large buoy. This case is considered.

3.3.6 Collision with a wind farm

Collisions of passing ships with wind farms resemble collisions with other fixed objects such as platforms and will be modelled accordingly.

Wind farms can in principle also be hit by dedicated vessels, as it is the case with platforms. However, visits of dedicated vessels are very rare compared to an oil platform. Given the low probability of a violent collision involving a leakage per visit, it is decided not to model the contribution from dedicated vessels.

3.3.7 Oil spill due to deliberate or inadvertent actions

The probability of deliberate or inadvertent oil spills in various parts of the Baltic Sea is modelled based on statistical data from HELCOM and – as far as necessary and available – national databases. The procedure is described in detail in Chapter 6.1.

In the statistical model all spills in the oil spill databases that can not be attributed to any of the other scenarios described in this section are attributed to deliberate or inadvertent spills. This is also the case for oil spills due to accidents at sea involving the smaller ships not analysed individually.

Two types of oil are considered:

- Gas oil and other oils where combat is not possible. This is exemplified by diesel.
- Other types of oil including condensate. This is assumed to be a high density oil, however, still floating on water. This is modelled by IFO 380, and the probability of floating just below the surface is set to zero.

Magnitude of spill:

- 0,3 t (< 1 t)
- 3 t (1 - 10 t)
- 30 t (10 - 100 t)

The spill is assumed to occur instantaneously. This simplification is in accordance with what was done for other scenarios.

Time of spill: As spill combat is not modelled for this type of spill, this is not required.

3.3.8 Spill during transfer of oil cargo at sea (STS operations)

Two scenarios are considered:

- Spill of oil from the loading system i.e. from hoses, valves etc. as well as overflow. This is modelled based on information retrieved from relevant national databases and a general experience with and analyses of transfer of liquids at sea, see Chapter 6.1.
- Spill of oil cargo (or bunker fuel) from tank(s) due to accidents at sea occurring in connection with the transfer. These incidents are considered in the same way as other accidents at sea, see Chapter 6.1.

3.3.9 Spill during bunkering at sea

Two scenarios are considered in the same way as described above, see Chapter 6.1.

4 Ship traffic

4.1 Introduction

Modelling the ship traffic in an appropriate way is one of the corner stones of the risk analysis. The model is based on AIS ship traffic data. AIS (Automatic Identification System) consists of position messages broadcast by each single vessel, with information on identity, position, speed over ground, course over ground etc. AIS has been introduced as part of IMO's International Convention for Safety of Life at Sea (SOLAS) (IMO, 1974) and is compulsory for all vessels with a gross tonnage of 300 tons or more. The intention is to increase the safety of vessels operating close to each other. In addition to this primary purpose, it is possible to collect AIS data by means of coast stations, which can be used to establish a comprehensive ship traffic database. The methodology described in this note requires the availability of such a database.

It is in the nature of such a database that it is very extensive and that its raw content cannot be applied directly in any ship accident risk model. This discrepancy is solved by generating a discrete route net covering the whole sea area and associating the individual AIS traces with the nearest net segments. The resulting route-based traffic description provides an unmatched basis for the following ship accident risk analysis.

The present chapter describes

- the applied/required data sources (Section 4.2)
- the AIS data analysis (including the generation of the discrete route net) and calibration (Section 4.3)
- the modelling of the flow of transported goods (Section 4.6)
- the approach used to obtain a prognosis of future traffic developments (Section 4.7)

4.2 Ship traffic data

HELCOM AIS

HELCOM's AIS data base is the primary data source for establishing the traffic model. It records AIS messages of all AIS-equipped vessels in the HELCOM area in six-minute intervals. Data are required for a 365-day period to eliminate seasonal differences and to provide statistically significant amount of data. A period lasting from 1 January to 31 December 2024 is chosen as reference period. This period has been chosen, because

- it is the latest available year

- winter 2023/2024 was cold and in the Fennoscandia the period from October to January was colder than average and thus the ice cover was large. In the future, more extreme weather conditions are expected: either very mild or very cold

- in this year AIS spoofing and falsified AIS locations were not that frequent that they would have biased the AIS data

Lloyd's Register

Lloyd's Register (LR) is a database containing information on a large number of parameters. Since every vessel has a unique IMO number, which is both used in LR and for AIS, it is possible to determine relevant vessel characteristics for the vessels recorded in the AIS data base (type, size, geometry, single or double hull etc.).

Other sources

To validate the AIS analysis, data from other data sources will be used. Especially data from VTS centres serve as an authoritative source of information that is independent of AIS data.

4.3 AIS analysis

4.3.1 Basics

The AIS messages sent by the vessels consist of position reports (POS) and static reports (STAT), as described in *Recommendation ITU-T M. 1371-1* issued by the International Telecommunication Union (ITU).

POS reports

POS reports are sent approx. every two seconds and contain information on vessel position, course, speed etc. In this reports, the ship is identified by its MMSI number.

STAT reports

STAT reports are sent every six minutes and contain information about the ship itself, amongst others MMSI and IMO number, name, call sign, size, actual draught, category of potentially hazardous cargo and position of the AIS transmitter relative to the ship.

Since the HELCOM database records AIS messages at six-minute intervals, it contains approximately an equal number of POS and STAT reports.

It has generally been observed that AIS reports, where vessels are supposed to enter data themselves are not always reliable. Information that needs to updated by the crew (cargo, actual draught, destination etc.) are therefore not necessarily valid, whereas automatically updated information (position, course, speed) can be expected to be more reliable.

4.3.2 Compression

With a frequency of six minutes, the POS reports represent position data at a distance of 1-2 nautical miles (2-4 km) and additional compression is not advantageous. However, it is not necessary to keep a correspondingly large number of STAT reports. Therefore, the data volume can be reduced by 50 %, considering that most STAT reports are redundant (this applied to 99.8 % of all STAT reports in 'Oil spill DK' (2007).

4.3.3 Compilation

Compiling the data for the further analysis means to link POS and STAT tables together, such that matching POS and STAT reports are identified. STAT reports contain information about the IMO number of a vessel (unique ID of the ship), which makes it possible to fetch further vessel characteristics from Lloyd's Register. This data structure is illustrated in Figure 4.1.

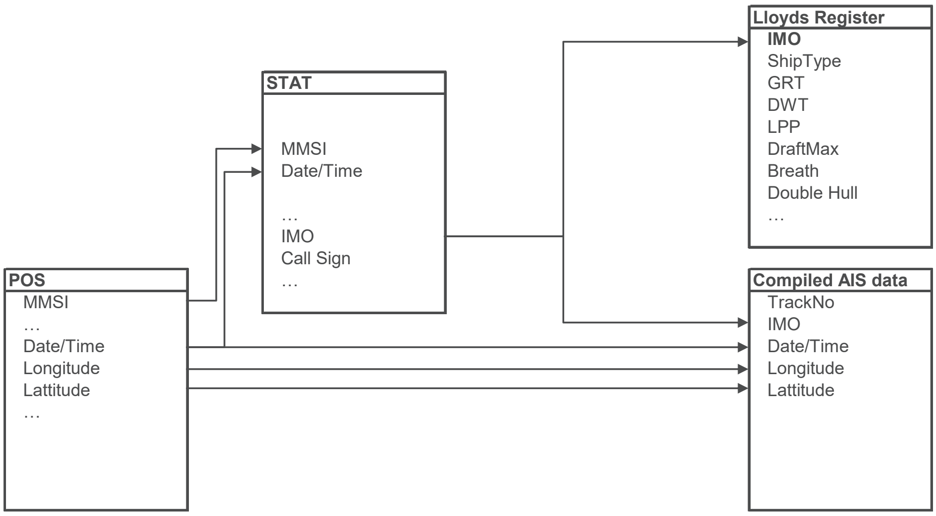


Figure 4.1 Data processing from raw AIS data (left) to the final basis of the analysis (right)

4.3.4 Traffic intensity

As a basis for the further analysis, it is necessary to determine the resulting traffic density for the entire Baltic Sea. This density should – apart from confirming a correct data processing – be suitable as decision basis for the generation of routes and the following data analysis (Section 4.3.5).

The density is determined by following the trace of a specific vessel – *long, latt* – and registering its path across a predefined quadratic grid. This approach is be implemented by simply rounding the trace coordinates to the nearest multiples of the cell length $\Delta long$ and $\Delta latt$ in the grid net (see Figure 4.2).

Even if the trace should have more than one POS report within each cell, only cell passages are counted. In this way, it is avoided to attribute more weight to slow ships than to fast ships in the density calculation. Moreover, anchoring vessels and vessels in harbours are kept from distorting the density plot (the approach corresponds to that used in commercially available AIS data programme packages).

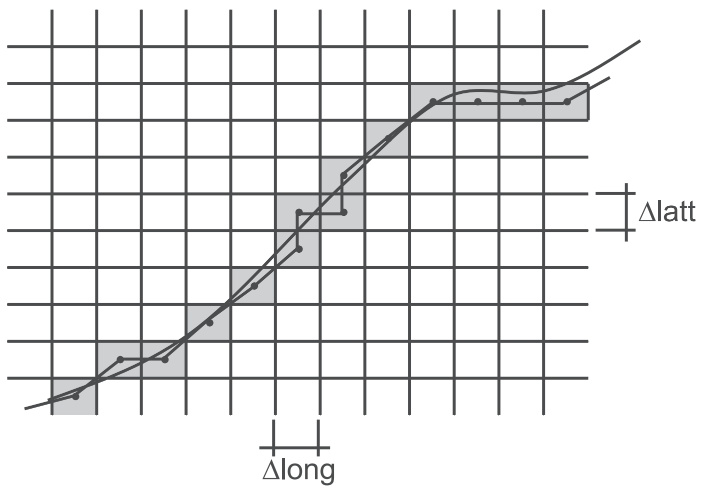


Figure 4.2 *Digitalisation of a vessel trace to determine the traffic density*

A simple density analysis of the recorded vessel passages yields a density plot as the one in Figure 4.3, where the traffic situation in the Baltic Sea in 2008-2009 is presented. The density was determined for a 500-metre grid.

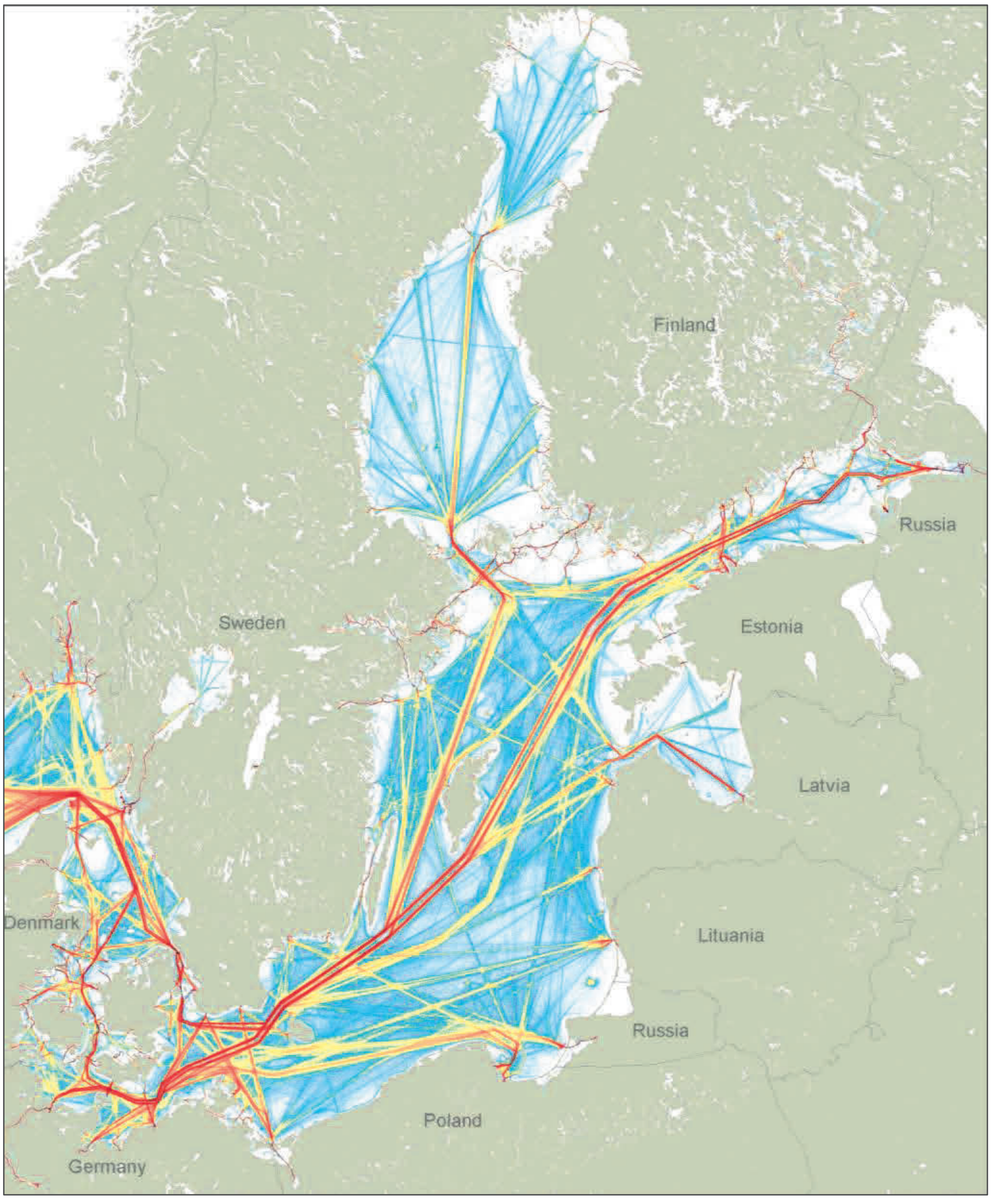


Figure 4.3 *Traffic density plot for the Danish EEZ based on the recorded traffic in 2008-2009 (BRISK I, 2011)*

4.3.5 Route generation and analysis

Ship traffic density tends to concentrate along more or less clearly defined routes. In the Danish example case in Figure 4.3, this tendency is especially evident, which is partly due to the narrow navigation channels. However, the tendency of following clearly distinguishable routes is general, since vessels always follow the most direct possible route between two destinations and since the number of relevant destinations is limited. This tendency can be clearly seen in the right edge of Figure 4.3, where traffic to and from the open sea east of Bornholm bundles in only 8 or 9 routes. On some routes traffic can be spread loosely to both sides of the route axis, but this does not cause any conceptual problems (compare ship collision model in Chapter 6.1)

Based on these considerations and considering the analysis-related advantages of a route-based traffic model, this modelling principle appears to be an obvious choice.

Route generation and analysis means:

- to define a geographic route net, which can represent the vessel movements in the Baltic Sea with good precision
- to analyse the route net mathematically, i.e. to determine the shortest possible paths through the net between two locations
- to map the AIS trace, i.e. to associate each AIS point with a route net segment.
- to determine various relevant statistics for each route segment, e.g. the distribution of the vessels' deviation from the route segment axis.

Definition of the route net

This work is done by manually creating a route net on a background map consisting of a density plot and a sea chart. This work is performed in a GIS programme (ArcGIS or similar). Once the route net has been defined, its geometry is exported to Excel for further analysis and to check its consistency (all route ends meeting in one node shall have the same coordinates).

Figure 4.4 shows the route net that was used for BRISK I (BRISK I, 2011). In general, a route net consists of two types of elements:

- nodes (defined by their longitude and latitude)
- route segments connecting the nodes

Figure 4.4 *The route net used in (BRISK I, 2011)*

Analysis of the route net

The route net defines different possible ways through the sea area and the concept of "the shortest way" between two nodes in the route net is a useful support function for associating the AIS points to route segments.

The shortest way between two nodes is determined by means of a simple iterative algorithm. The results are deposited in two separate matrices. One of them contains the shortest way from node *i* to node *j*. The other contains the length of the shortest way from node *i* to node *j*.

Systematic mapping of the AIS traces

With the above-described basis it is possible to map the individual AIS traces systematically. As a first step, it needs to be defined, when a trace – i.e. a sequence of AIS points – can be concluded to represent a coherent journey. This definition needs to take the possibility of data transmission interruptions into account (see Figure 4.5). It would simplify the mapping procedure significantly to neglect missing sequences. However, this would result in a systematic underestimation of the traffic in certain area, if e.g. one local coast station has been out of order during a certain period of time. Furthermore, information about the total journey and its origin and destination would get lost.

Figure 4.5 Example of AIS points of an identified trace with pronounced transmission interruptions

Therefore, the mapping procedure is refined to handle interrupted traces and to interpolate the missing sections. When an individual trace is identified, the following conditions are applied:

- The time difference between two successive AIS points must not exceed 4 hours
- An approximate vessel speed v_{appr} is calculated as the distance between two points divided by the time difference between the two messages. The two points are considered as part of the same trace if
  - $v_{appr} > 0$ knots (the ship does not stand still)
  - v_{appr} is finite (i.e. not very large, which would indicate an unrealistic jump and therefore an error)
  - $v_{appr} > 0.6 \times v_{avg}$, where v_{avg} is the average speed that has been observed earlier on the trace

With these conditions, the most significant errors are filtered away and the trace is not interrupted, if the vessel stops. The latter is chosen to obtain two separate traces in case a vessel is lying at a port.

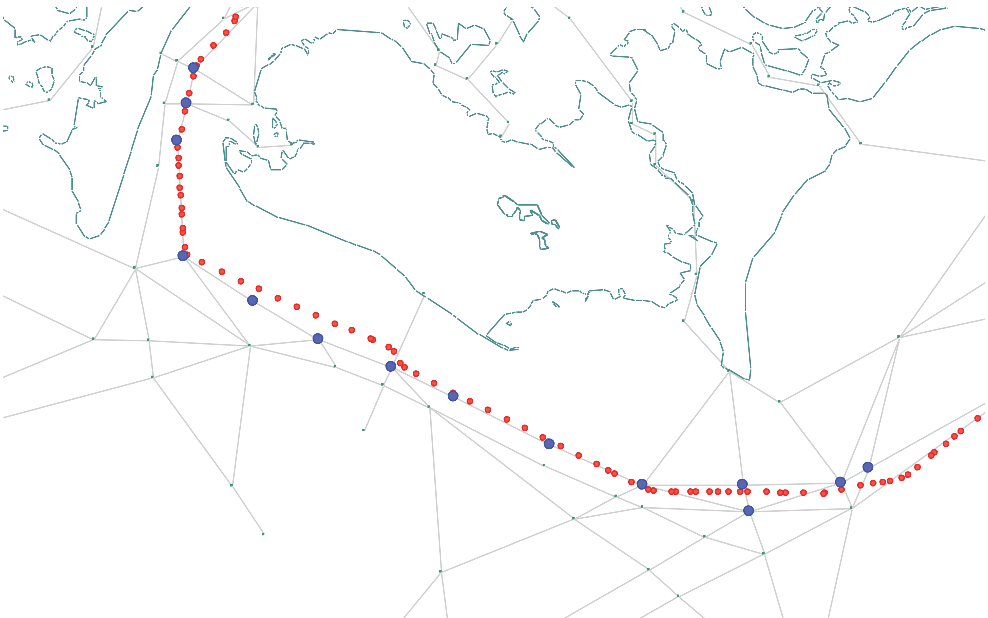


Figure 4.6 Determination of which nodes in the route net are close to the AIS trace

When a sequence of AIS points has been recognised as a continuous trace (as shown in Figure 4.5), an algorithm regards the point sequence and it is determines, which nodes are passed at the closest distance (see Figure 4.6).

Once the sequence of nodes in the route net has been determined, another algorithm removes unrealistic outcomes caused by the mathematical logics in the first algorithm (see Figure 4.7). Another typical misinterpretation are vessels that seem two sail into a “dead end”, i.e. by following a route segment first in one direction and then into the opposite direction before continuing. This error is equally removed.

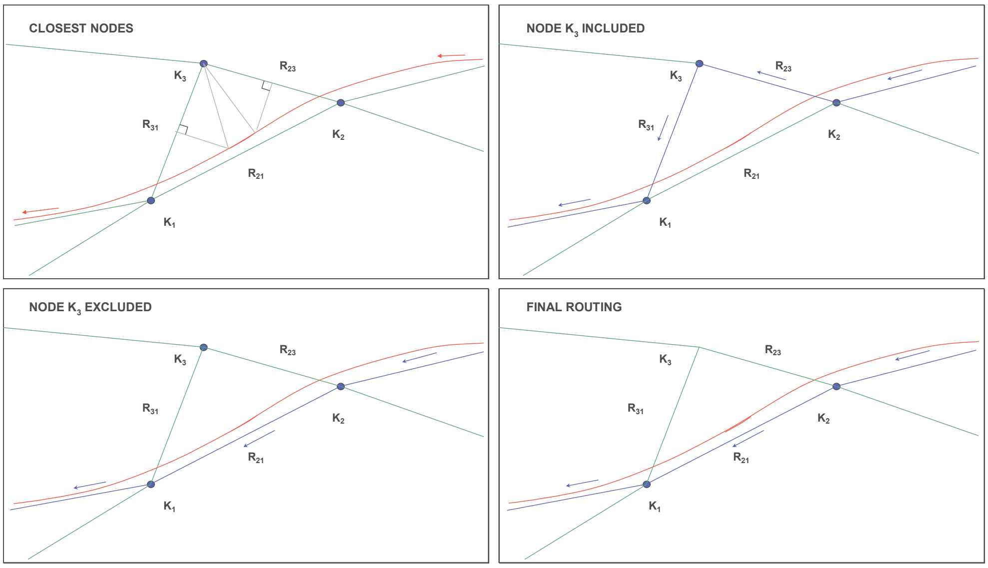


Figure 4.7 An example showing how the closest node (K_3) can mislead the mapping algorithm

Statistics

During the route mapping procedure it is determined, which AIS points can be associated with which route segment passages. This information is subsequently used for determining the mean value and spreading of the average geometrical distance between the points and the ideal line in the route net. These statistics are required for the calculation of the collision frequency of vessels sailing along the same route segment (compare Chapter 6.1).

The obtained mean value and spreading estimates from a section of the Kattegat (Oil spill DK, 2007) are illustrated in Figure 4.8 together with a plot of the traffic density. It can be seen that there is a good consistence between the mean value/spreading estimates and the shape of the routes in the density plot. One essential observation is that the statistics describe the traffic correctly even there, where a (manually defined) route segment does is not match the route in the density plot precisely. This shows that the traffic model is not overly sensitive with respect to the precise definition of the route segments.

It can equally be seen that heavily frequented routes tend to use very narrow corridors with very little spreading. Conversely, routes with very low traffic density and very weakly distinguished traffic corridors are characterised by a large spreading.

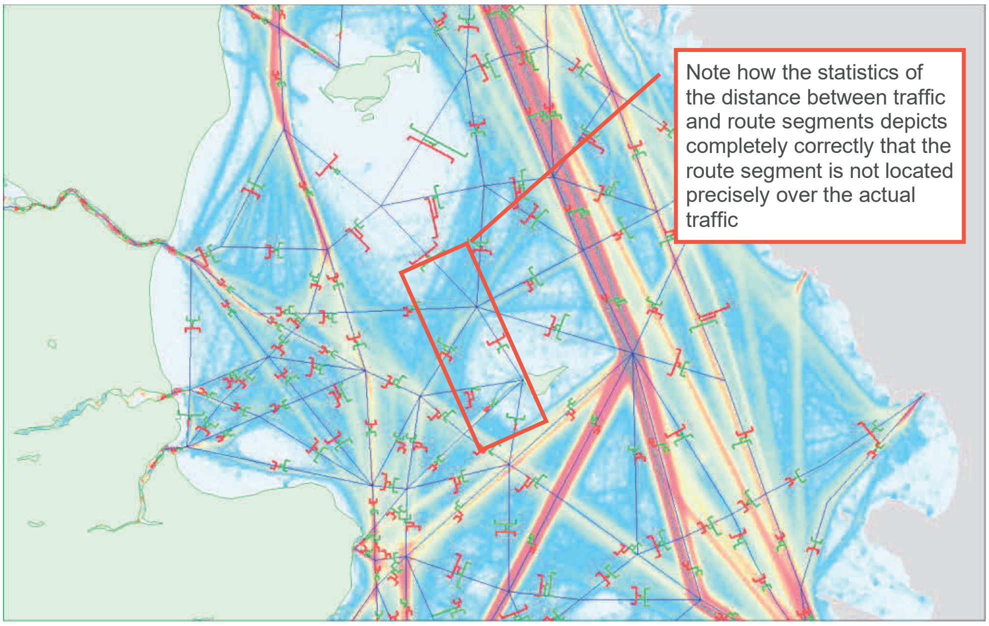


Figure 4.8 *Graphic illustration of the mean value and spreading of the distance between vessels and route segment axes. For each route segment and each direction (red/green), an interval covering the average and ± ½ the spreading is shown (Oil spill DK, 2007)*

4.3.6 Calibration

The relatively complex analytical procedure will inevitably lead to loss of traffic information. The reasons for this can amongst others be:

- periods, during which AIS point data (POS reports) are missing or incomplete
- vessels that do not send correct AIS information (STAT reports) and that cannot be identified therefore
- rejection of AIS points that do not yield qualified traces and cannot be mapped
- rejection during route analysis, because it is not possible to account for all data errors or for traces that are very inconsistent with the route net.

The traffic that has been mapped on the route net will give sensible traffic patterns and distributions, whereas the absolute numbers – e.g. the yearly traffic volume on specific routes – will underestimate the actual situation. Since it can be expected that the error sources affect the entire traffic picture in the same way – both with respect to geography and ship types – these lost data can be compensated by resizing the entire mapped traffic volume up accordingly.

AIS outages

To identify AIS outages, the number of POS reports per day is plotted as a function. In this way, outages become evident very quickly and can be compensated by means of a calibration factor f_1. In the case of (BRISK I, 2011), this factor was equal to 1.0082, i.e. the traffic volume needed to be resized by 0.82 %.

For the current project, the factor needs to be determined anew. It can be a good idea to plot a separate POS function for each major geographic area. In this way it can be avoided to dilute local outages beyond recognisability.

In addition to this, the method previously used would not catch ships with inactive AIS transponder. This was not a major issue back in 2008-2009 but has become more common these days. Therefore, the AIS number also need to be calibrated against independent records of ship passages such as those provided by VTS centres.

Route definition and analysis

The reduction of the mapped AIS reports – and therefore of the traffic volume – that follows from the elimination of traffic data where:

› the vessel cannot be identified or

› it is not possible to define a qualified trace or

› the route analysis cannot be performed, because the AIS data and the route net are not sufficiently compatible

is examined by comparing the traffic volume with passage statistics based directly on raw AIS data. These passage statistics are obtained by counting how many observations can be made, where two successive AIS points from one vessel are located each on one side of a virtual passage line. This will produce a second calibration factor f_2.

The total calibration factor for both effects is obtained as

$$F = f_1 \times f_2$$

It is introduced separately for each single route passage (i.e. each single vessel movement on a route):

IMO	TrackNo	Time	RuteSegment	F
…	…	…	…	…
9274616	186144	12/16/05 10:01	-88	1,195
9274616	186144	12/16/05 10:07	-87	1,195
9274616	186144	12/16/05 10:24	61	1,195
9274616	186144	12/16/05 10:55	1079	1,195
9274616	186144	12/16/05 11:13	1080	1,195
9274616	186144	12/16/05 11:32	27	1,195
…	…	…	…	…

This approach has the advantage that other factors, such as prognoses of the future traffic development can easily be implemented (compare Section 4.7).

4.3.7 The resulting traffic model

The resulting traffic model is essentially described as a database table containing all identified route passages (events, where a vessel passes a route segment) combined with information about passage direction and vessel characteristics from Lloyd's Register and a corresponding table containing the calibration factor *F*. Using this detailed model has the following advantages:

- traffic surveys can be performed very flexibly based on the detailed ship characteristics from Lloyd's Register
- the actual journeys of the respective vessels are contained in the description, since sequences of route passages are tied together by a common track number and the date information
- conditional traffic patterns – e.g. an overview of all traffic in the entire Baltic Sea sailing to or from the Kiel Channel – are relatively easy to provide
- the passage of the vessels through the respective nodes in the route net – i.e. on which route segment does a vessel arrive at a node and on which route segment does it continue – are contained in the description and can be used in the ship collision model

The database provides traffic data for the calculation of accident and spill frequencies, which are directly dependent upon the traffic, its volume and composition.

To display the content of the traffic model, different tables can be extracted – the aggregated transport activity (sailed nautical miles) and the distribution of the traffic on specific routes to different ship types and sizes.

Classification of ships

The information on the identified vessels that can be found in Lloyd's Register is more detailed than what is meaningful in the context of the risk analysis. This broad classification is reduced to 24 different types as shown in Table 4.1. Type 25 "unknown" is not used in the final traffic model but is used to classify the remaining group that cannot be identified during the model establishment.

Table 4.1 Ship types used in the model (left) and general groups of types used for preparing statistics and results (right)

Type ID	Type description	Vessel group	Type description
1	Work vessel	Tankers	Bulk/oil
2	Car transport		Tanker, food
3	Bulk		Tanker, gas
4	Bulk/Oil		Tanker, chemical/prod.
5	Container		Tanker, chemical
6	Fishing vessel		Tanker, product
7	Ferry		Tanker, crude oil
8	Ferry/Ro-Ro		Tanker, others
9	Cruise ship	Bulk carriers	Bulk
10	Reefer	General cargo	General cargo
11	Nuclear fuel	Packed cargo	Car transport
12	Offshore		Container
13	Ro-Ro		Reefer
14	Tug		Nuclear fuel
15	General cargo		Offshore
16	Navy		Ro-Ro
17	Tanker, food	Ferry and pass-	Ferry
18	Tanker, gas	anger traffic	Ferry/Ro-Ro
19	Tanker, chemical/products		Cruise ship
20	Tanker, chemical	Others	Work vessel
21	Tanker, product		Fishing vessel
22	Tanker, crude oil		Tug
23	Tanker, others		Navy
24	Others		Others
25	Unknown		Unknown

4.4 Ice and ice-free seasons

4.4.1 Effects of sea ice upon ship traffic

Sea ice during winter is a major issue when regarding the Baltic Sea as a whole. Ice channel navigation has a number of effects upon traffic patterns:

› In ice-covered sea areas, ships are essentially bound to use routes with ice channels, i.e. many summer routes will not have any traffic. In general, traffic intensity per route and time unit is different than during the ice-free season.

› Total traffic intensity differs between ice and ice-free season because many journeys are postponed until the end of the ice-season.

› Traffic spreading relative to the route axis is affected both by the shape of the ice channel and the usage of ice-breaker convoys.

› The distance between ships following the same direction is affected by the usage of ice breaker convoys.

These effects influence the accident frequency and thus the frequency of spills (see Chapter 7). To account for them the procedure described in the following section is used.

4.4.2 Implementation in the traffic model

Route pattern

The approach described in Section 4.3 models the traffic as a discrete route net (Figure 4.3) which is established based on the observed traffic intensities (Figure 4.4). To include the effect of ice channel navigation in the route layout it is necessary to

› create an AIS ship density plot for the ice-free part of the year

› create an AIS ship density plot for a period of time, where it is known that the sea was in fact covered by ice

› based on these two plots, establish a route net that is able to reflect both states (for methodological reasons, establishing two separate route nets would be very unpractical)

Intensity and spreading along routes

Each route is analysed with respect to traffic intensity (number, type and size of ships) as well as straying relative to the route axis (see Figure 4.8). It is necessary to perform a separate analysis for the ice seasons and the ice-free season each. Since the beginning and duration varies from year to year, it is proposed to establish separate traffic statistics for the ice season and the ice-free season for the data collection year. It is necessary to analyse AIS data from a year with a “typical” ice season, i.e. an ice season coming close to the average duration. Of all winters since the introduction of HELCOM AIS, winter 2008/2009 comes closest to this definition. Therefore, the data period is chosen as 1 July 2008 to 30 June 2009.

Nevertheless, there will inevitably be a difference between the average ice season duration and the duration in 2008/2009. This could in principle be corrected by assuming that the traffic intensity per unit of time is constant during the ice season, regardless of its duration. Since the total number of voyages per year is more or less independent of the ice season duration, it is then possible to calibrate the traffic intensity during the ice-free season accordingly. However, such an approach leads to some principal methodological complications, due to the fact that only part of the Baltic Sea is frozen and that there is a mixture of local and trans-regional traffic both in the frozen and the ice-free part of the Baltic Sea. Therefore, no additional correction is made.

In the Gulf of Finland, ice appears first in the east and spreads westwards afterwards. In the less heavily navigated Gulf of Bothnia ice spreads from the north to the south. Therefore, there is no precise “beginning” and “end” of the ice season. Nevertheless, it is proposed to pretend as though this was the case for reasons of methodological simplicity.

The effect of short distances between ships in ice-breaker convoys is modelled directly in the accident model, see Section 7.2.3.

4.5 Geographical division into sub-regions

Sub-division into areas

The Baltic Sea is divided into sub-regions that have relatively homogeneous conditions, e.g. with regards to hydrography, ship traffic intensity, and environment.

Trans-national areas

In several cases the traffic routes are almost identical with the borders between national EEZs. This is the case e.g. in Fehmarn Belt and Kadetrenden (between Denmark and Germany) or in The Sound (between Denmark and Sweden), in the Gulf of Finland (between Finland and Estonia) and in the Gulf of Bothnia (between Sweden and Finland). It obvious from a methodological point of view (ship route and collision modelling, Chapters 4 and 7) that the sub-regions comprise of areas from two or more EEZs. The trans-national agreements that will be developed in a separate task of the present project shall provide the diplomatic and legal background for effective co-operation during clean up-operations in the different sub-regions.

Figure 4.9 presents the sub-divisions introduced during BRISK I (BRISK I, 2011). It is the intention to use the same sub-division for BRISK II, however with the change that the Russian EEZ will only be treated to a limited extent, cf. Section 1.3.

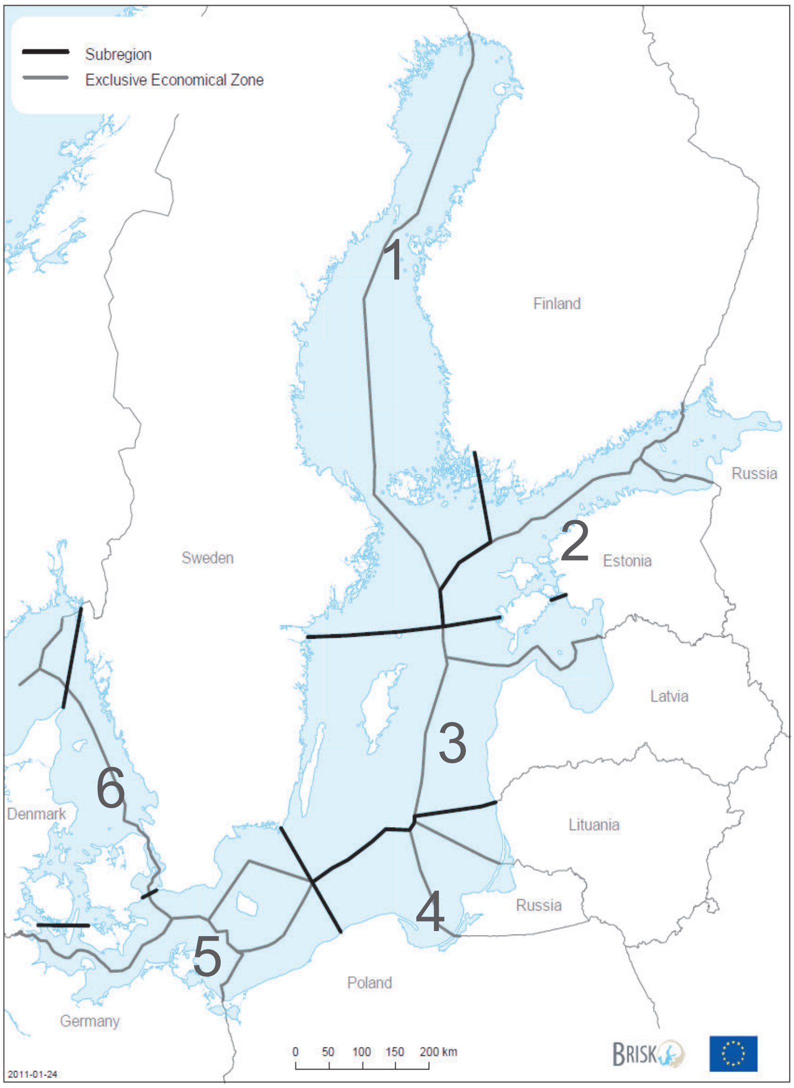


Figure 4.9 *Sub-division of the Baltic Sea (BRISK I, 2011)*

4.6 Flow of goods

Information about the vessel cargo load is of vital importance for predicting, which substances can be released into the maritime environment in case of an accident at sea. Traffic information contained in the recorded AIS data (STAT messages) can comprise information about the classification of the cargo of a vessel, but the data are not sufficiently detailed and reliable to be applied in the risk analysis. Therefore, the vessel cargo needs to be investigated in more detail based on other databases. This material is separately treated in Chapter 5, where a method is for predicting the cargo of a vessel based on its load situation based on the traffic model

Only substances and cargo types that are supposed to have a significant impact upon the environment are included in the model. The choice of these substances is described in Chapter 5, where a number of cargo groups are defined to represent the cargo aboard bulk carrying vessels. The cargo groups are identified by a number and a representative substance, see Table 4.2.

Type 0 (bunker oil incl. lubricants) is not a cargo type but represents the oil products used for propulsion and maintenance on all vessels. This means that this type of substance can be released from any vessel in case of an accident at sea. Categorising these substances alongside with those substances that can be transported as actual cargo leads to an advantageous data structure with regard to the further spill analysis process.

Table 4.2 List of substances used in the modelling of vessel cargo and bunker oil

Type	Representative substance
0	Bunker oil, lubricants
1	Vinyl chloride
5	Benzene
7	Toluene
8	Acetonecyanhydrine
9	Acrylonitrile
10	MTBE
11	Methanol
12	Tar
13	Molasses
14	Betonies
16	Others
18	Vegetable and animal oil
19	Crude oil
20	Fuel oil
21	Gasoil, diesel, petroleum, jet fuel and light fuel oil
22	Gasoline

The developed method for tying cargo types to the ship traffic describes the probability of encountering a given cargo type depending on:

- the area (as defined in Section 4.5)
- the orientation of the route and the direction in which the vessel uses the route. Based on the principles described in Section 5.6, different descriptions of the load state and cargo type of the vessels are established, depending on whether the vessels are sailing into the Baltic Sea or out. This is actually one

of the reasons, why an “in” and an “out” direction is defined for each route segment. In this way, the description can be used generally, despite of the fact that not all journeys actually enter or leave the Baltic Sea.

› the ship type and size

Table 4.3 provides an example for this type of specification for a vessel sailing through The Sound in ingoing direction (i.e. sailing into the Baltic Sea). Based on this type of table the probability of a certain substance being aboard a given vessel can be calculated for each route segment in the entire Baltic Sea.

Table 4.3 Example of specifying the probability that a vessel is carrying a different substances (Øresund Ind = The Sound, ingoing) (Oil spill DK, 2007)

Område	Skibstype	DWT_{MIN}	DWT_{MAX}	P_{LOAD}	P_{BALL}	$P_{CG\,1}$	$P_{CG\,5}$	$P_{CG\,7}$	$P_{CG\,8}$	$P_{CG\,9}$	$P_{CG\,10}$	$P_{CG\,11}$	$P_{CG\,12}$	$P_{CG\,13}$	$P_{CG\,14}$	$P_{CG\,16}$	$P_{CG\,18}$	$P_{CG\,19}$	$P_{CG\,20}$	$P_{CG\,21}$	$P_{CG\,22}$
Øresund Ind	Bulk	0	500	60.0%	40.0%						8.0%				2.0%	90.0%					
Øresund Ind	Bulk	500	3,000	60.0%	40.0%						8.0%				2.0%	90.0%					
Øresund Ind	Bulk	3,000	10,000	60.0%	40.0%						8.0%				2.0%	90.0%					
Øresund Ind	Bulk	10,000	25,000	6.7%	93.3%						8.0%				2.0%	90.0%					
Øresund Ind	Bulk	25,000	100,000	6.7%	93.3%						8.0%				2.0%	90.0%					
Øresund Ind	Bulk	100,000			100.0%																
Øresund Ind	Bulk/Olie	0	500	50.0%	50.0%											90.0%		2.5%	2.5%	2.5%	2.5%
Øresund Ind	Bulk/Olie	500	3,000	50.0%	50.0%											90.0%		2.5%	2.5%	2.5%	2.5%
Øresund Ind	Bulk/Olie	3,000	10,000	50.0%	50.0%											90.0%		2.5%	2.5%	2.5%	2.5%
Øresund Ind	Bulk/Olie	10,000	25,000	50.0%	50.0%											90.0%		2.5%	2.5%	2.5%	2.5%
Øresund Ind	Bulk/Olie	25,000	100,000		100.0%																
Øresund Ind	Bulk/Olie	100,000			100.0%																
Øresund Ind	Tanker, Gas	0	500	72.7%	27.3%	100.0%															
Øresund Ind	Tanker, Gas	500	3,000	72.7%	27.3%	100.0%															
Øresund Ind	Tanker, Gas	3,000	10,000	72.7%	27.3%	100.0%															
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

4.7 Prognosis

In addition to analysing the present traffic situation, the future development needs to be taken into account to provide a sound basis for sustainable decision-making.

Therefore, the situation in 2036 will be modelled as a scenario in addition to the present-day scenario. This requires a realistic prognosis of the traffic development in the meantime.

4.7.1 Data

In BRISK I (BRISK I, 2011), the prognosis was based on the following sources of information:

› National data on historical transport development and/or prognoses

› The Baltic Marine Outlook 2006, containing a traffic forecast reaching until 2020

› Clarkson Register

› Lloyd’s Register

These or comparable data will be required in the present case again. The specific data requirements will be indicated in the data collection note.

4.7.2 Definition of ship types

The ship types described in Table 4.1 need to be reflected in the prognosis. However, the available prognoses envisage transport volumes within certain market segments rather than for certain ship types. Therefore, the 25 ship types are attributed to 13 marked segments, as shown in Table 4.4.

Table 4.4 Division of ships into market segments for the analysis

Main group for prognosis	Market segment	Vessel type (as in Table 4.1)
Cargo transport	Cars	Car transport
	Containers	Container
	Ro-Ro	Ro-Ro
	Bulk cargo	Bulk
	Liquefied natural gas (LNG)	Gas tanker
	Chemicals	Chemical tanker, other tanker
	Oil transport	Chemical/product tanker, product tanker, crude oil tanker, bulk/oil
	General cargo	General cargo
	Food tanker	Food tanker
	Reefer	Reefer
	Others	Offshore, work vessel, fishing vessel, tug, navy, nuclear fuel, others, unknown
Passenger transport	Route passenger transport	Ferry, ferry/Ro-Ro
	Cruise	Cruise ship

4.7.3 Approach

When goods and passenger transport volumes at sea are rising, this does not necessarily imply that the number of ship movements is increasing. In fact, it can be observed that the number of ships tend to remain somewhat constant, whereas the average ship size is steadily increasing (BRISK I, 2011). Therefore, both the volume of transported goods and passengers *and* the fleet development need to be taken into account.

Fleet development

As a first step, the development of the global fleet is analysed. In 'Oil spill DK' (2007), the development of the average ship size during 1995-2000 and during 2000-2005 was regarded for each vessel type based on Clarkson Register and Lloyd's Register. It is proposed to use the same reference period for the present project.

Next, the global development is transferred to the regional situation in the Baltic Sea. This work step consists of the following consecutive tasks:

- Definition of a few main inter-regional traffic streams
- Analysis of size restrictions on each of these traffic streams (draught and length restriction at the entrances to the Baltic Sea, port characteristics etc.)
- Estimation of the future development of average ship sizes based on global trends in the past, local restrictions (draught etc.) and expert judgement

Cargo transport

The prognosis of future cargo transport is modelled in eight steps:

1. The basic import and export data for a reference year as close to 2024 as possible are obtained from a high-level economic prognosis study. For BRISK I, the now outdated Baltic Maritime Outlook 2006 dealing with the prognosis year 2020 was used). The data situation will be investigated as part of task 2.2 *Data collection*.
2. A prognosis of the development up to 2036 or a nearby year is obtained from the same source as in item 1.
3. The cargo types from the data source are attributed to three main cargo groups (dry bulk/liquid bulk/other)
4. Based on step 1 to 3 the annual growth of transported tonnage is estimated for each main cargo group
5. In addition to the analysis in step 4, there is the possibility of performing supplementary analyses for the most important shipping segments
6. The main cargo groups are attributed to the vessel types in Table 4.1
7. The corresponding increase in ship movements is corrected by the effect of growing average ship sizes (see Fleet development above). Furthermore, the prognosis is corrected for imbalances between import and export: If import is larger than export for a given product at a given port, additional export will not lead to additional ship movements. Instead, the partly loaded outbound ships will have a higher loading percentage.
8. The prognosis is performed based on the information in step 1 to 7.

Apart from this prognosis, some currently ongoing major projects in the Baltic Sea equally involve ship traffic prognoses. These developments will be observed and potentially considered in the prognosis for the BRISK II project.

Passenger transport

Based on any available data on historical developments as well as prognoses collected under Task 2.2 Data collection the following task are carried out:

- the present situation is established.

- Future development is assessed for each major ferry and Ro-Ro route separately, based on historical trends as well as on considerations about future changes in the infrastructure (e.g. construction of the Fehmarn Belt fixed link).

In the case of cruise traffic, separate estimates are performed based on observed annual growth rates both on a global and a Baltic level.

4.7.4 Implementation in the model

In the model, the expected future traffic increase is implemented by modifying the factor *F* that has been introduced in Section 4.3.6.

5 Transport of oil and hazardous substances in the Baltic Sea

5.1 Definition of oils and chemicals

The definitions of “oils” and “chemicals” given below are used throughout the study.

5.1.1 Oils

An oil is defined as:

› Any form of mineral oil or mixtures of oil including crude oil, condensates from natural gas, oil sludge and oil waste as well as fuel oil and other refined products, except petro chemicals which are defined as chemicals. This definition is in accordance with the definition of oil in MARPOL Annex I (IMO, 1987a), in which it is said that petro chemicals come under MARPOL Annex II (IMO, 1987b).

› Any form of animal or vegetable oil.

5.1.2 Chemicals

A chemical is defined as:

› Chemical compounds and products coming under the International Maritime Dangerous Goods (IMDG) code (IMO, 2002) or classified in accordance with the classification system in MARPOL Annex II (IMO 1987b).

Some oils come under the IMDG rules, but are excluded the definition as chemicals in accordance with what was said for oils. The same is the case for animal or vegetable oils.

The IMDG code contains detailed technical specifications to enable dangerous goods to be transported safely at sea. The code includes rules for packing, handling, loading/unloading and stowage of dangerous goods. The code classifies dangerous goods according to nine classes:

1 Explosives

2 Gases

3 Flammable liquids

4 Flammable solids

5 Oxidizing substances and organic peroxides

6 Toxic and infectious substances

7 Radioactive material

8 Corrosive substances

9 Miscellaneous dangerous substances and articles.

5.2 Information on sea transport (overlook of sources)

Sources of information on transport of oil and chemicals through the Baltic Sea need to be identified and assessed considering their usefulness.

In the following, it is shown which sources have been used for BRISK I (BRISK I, 2011). Some data (AIS) are available throughout the Baltic Sea region. Other sources are country-specific. Here, the Danish data sources are described to facilitate the identification of similar data sources in the other HELCOM member countries.

The following sources were used in BRISK I (BRISK I, 2011):

- SHIPPOS
- Port data

VTT's reports on chemicals transport (VTT, 2004) and oil transport in the Gulf of Finland (VTT, 2006). For BRISK II, it is planned to use the following data:

- Port data
- Data from VTS centres and similar entities

A large number of additional sources in particular regarding transportation of chemicals have been consulted but these do not provided information of additional use.

Based on AIS data a description of the traffic is set up differentiating on size and type of vessel. Combining this information with the results of an analysis of the information from ports and VTS centres yields information on how the various types of bulk cargo is distributed on type of ship.

5.3 Grouping of oils and chemicals

5.3.1 Course of a spill to the sea

An important parameter for the analysis of the risk of pollution of the marine environment is how the oil of chemical spilled will act in contact with sea water. This is important to assess both the potentially harmful consequences as well as the chances of limiting the damage.

From an overall point of view 6 possible courses exist:

1 Evaporates

2 Reacts

3 Floats

4 Floats sub-surface

5 Dissolves

6 Sinks

The behaviour of a spill may be determined from the compounds physical parameters. The definitions on which the grouping within the present study has been based are indicated below.

Evaporates: Gaseous compounds at atmospheric pressure and a temperature of 20 ºC and rather insoluble in water (see soluble).

Reacts: Compounds reacting chemically with water.

Floats: Compounds rather insoluble in water (see soluble) and having a density of less than 0.9 kg/l.

Floats sub surface: Compounds aggregating and floating somewhere below the sea surface. The compounds are relatively insoluble in water (see soluble) and has a density between 0.9 kg/l and 1.028 kg/l. True compounds of this nature are only compounds with a density between 1.006 kg/l and 1.028 kg/l, which is the span of density of sea water in Danish waters (variation in density of sea water with a salinity of 7 ‰ - 35 ‰ PSU). Outside this interval of density temporary sub surface floating may occur when fractions of the spill temperately are beaten down in the water by turbulence. This is, however, subject to conditions of wave height, salinity etc.

Soluble: Compounds are considered soluble in water if less than 100 parts of water to is required to dissolve 1 part of the compound

Sinks: Compounds rather insoluble in water (see soluble) and having a density above 1.028 kg/l.

5.3.2 Hazardous properties

The dangerous properties of the compound include fire hazards, health hazards and hazards to the environment - and any combination of these. Within the rules of

IMDG the compounds are classified into one of the nine classes according to their dominating hazardous properties.

Flammable gases are in general classified as group 2. Flammable liquids and solids are classified as group 3 and 4. However, flammable compounds may also be found in other classes.

Environmental harmful compounds and compounds posing a health hazard are found in all classes. Dangerous chemicals classified based on their environmental hazards alone are found in class. 9.

Considering classification of environmental hazards the rules for transportation of chemicals in bulk are to be observed.

Noxious liquid substances carried in bulk are categorized based on the rules set in MARPOL. The new classification, which came into force in 2007 includes four classes:

- Category X: Noxious liquid substances which if discharged into the sea … are deemed to present a major hazard to either marine resources or human health and, therefore, justify the prohibition of the discharge into the marine environment.
- Category Y: Noxious liquid substances which if discharged into the sea … are deemed to present a hazard to either marine resources or human health or cause harm to amenities or other legitimate uses of the sea and, therefore, justify a limitation on the quality and quantity of the discharge into the marine environment.
- Category Z: Noxious liquid substances which if discharged into the sea … are deemed to present a minor hazard to either marine resources or human health and, therefore, justify less stringent restrictions on the quality and quantity of the discharge into the marine environment.
- Other chemicals: Substances which have been evaluated and fall outside Category X, Y and Z because they are considered to present no harm to marine resources, human health …

Oils and chemicals which are floating or sinking (liquid or solid and relatively insoluble in water) and which are not already classified are in accordance with the MARPOL classification also considered being potentially harmful to the environment.

5.3.3 Interaction of physical properties

Assessing the risk of spills of oil and chemicals to the sea the interaction between the compounds physical properties, its harmful properties and the sea water is of major importance.

In practice it will normally only be possible to combat spills floating or sinking, while combat of water soluble compounds primarily may be effective in smaller bounded areas. Oil and chemicals floating below sea surface can not be fought with known techniques.

Oil or chemicals harmful to the environment and either soluble or floating below sea surface are thus particularly problematic considering risk mitigation. Environmentally harmful compounds evaporating are not immediately critical considering the marine environment as these compounds will "disappear" shortly.

Oil and chemicals constitution a health or fire hazard are of relevance considering the risk to the emergency forces combating the release.

In case the emergency forces are not equipped with protective clothing, breathing apparatus and like to protect the personnel it may be required to keep the personnel at some distance to the spill. This may mean that a spill which could have been effectively mitigated in theory was not.

Several different substances may be spilled at the same time. Considering bulk cargoes only one compound is transported, while vessels carrying packaged goods may transport several different compounds. This means that normally in incidents involving loss of packaged goods there will be a chance of simultaneous spills of several hazardous chemicals. The present study does not consider this further.

5.3.4 Grouping to be applied in the present study

Classification considering behaviour after spill to the sea

For use in the assessment of the emergency preparedness the compounds are grouped considering their behaviour when spilled into the sea:

- Evaporates
- Reacts
- Floats
- Floats sub surface
- Dissolves
- Sinks

A representative set of cargos of oil and chemicals is set up and assigned to the ship traffic: The compounds transported, the amounts, transport mode etc. is based on a detailed analysis of the actual transportation pattern including routes and types of ship. This serves as input for the risk analysis.

Classification of danger

As a basis for further modelling the chemicals are grouped considering their hazardous properties:

- Fire hazard
- Health hazard
- Environmental hazard

Each of these classes is further subdivided into three subclasses: Very hazardous, hazardous and not hazardous. The three classes are appointed a colour visualizing the hazard level: Red = Very Hazardous, Yellow = Hazardous and White = Not Hazardous.

5.4 Oil compounds selected for modelling

5.4.1 Oil cargos

Modelling of tank vessels is done combining information from SHIPPOS or a comparable national database and Lloyd's Register. IMO number, type and size of ship are attributed to the SHIPPOS registrations. Routes of transportation are then obtained by combining this information with the AIS/SHIPPOS data.

The information retrieved comprises:

- Type of cargo
- For each type of cargo the number of tank vessels and the typical size of cargo in tonnes

The cargo is grouped into the representative types indicated in the table below. Information is an example valid for Danish waters only.

Table 5.1 Cargo types for tank vessels

Group	Fraction of tank vessels	Typical size of cargo
Crude oil including condensate	25-35% in the Great Belt	90.000 t
Fuel oil including bunker fuel	25-30% in the Great Belt and 15% in The Sound	50.000 t
Diesel, jet fuel and heating oil	25-30% in the Great Belt and 40% in The Sound	30.000 t
Petrol and naphtha	10% of the Great Belt	30.000 t
LPG and propane	25-30% in The Sound	-
Oil products	5% in the Great Belt	.
Vegetable oil	2%	-

5.4.2 Oil carried for the use of the ship

Oil for the use of propulsion is stored in the ship's fuel tanks. The capacity of these tanks is typically in the range of between 2.000-10.000 t. For container vessels the tanks may be as large as 15.000 tons. The tanks constitute a potential source of oil pollution.

Fuel is available in a number of grades with a rather large difference in price. Typically larger ships would use heavy (residual) oil which is less costly than refined products (diesel), used by smaller ships. The following distribution on fuel types was used (O.W. Bunker, 2006):

- IFO 380: 75%
- IFO 180: 10%
- Refined products: 15%

5.4.3 Modelling of oil

Based on the information about the amounts transported and the physical behaviour in case of a spill to the sea the following substances are selected to be modelled representing oil:

- Crude oil and fuel oil (always considered to be liquid)
- Diesel
- Petrol
- Vegetable and animal oil
- IFO 380 (and a probability of sub surface floating).

IFO 380 is representing both IFO 180 and IFO 380. The probability of sub surface floating is set considering this.

The hazard classification indicated below is applied.

Some types of crude oil and petrol may be classified as toxic due to their contents of benzene. In case of a spill the majority of the benzene would evaporate shortly reducing the concentration. Thus, both crude oil and petrol was classified “yellow”, i.e. “hazardous”.

Table 5.2: Grouping of oil including colour classification of hazards to the environment, health hazard and fire hazard

Oil	Behaviour in case of a spill to the sea	Environmental hazard	Health hazard	Fire hazard
Cargos				
Crude oil and fuel oil	Floats, possibly sub-surface			
Diesel, jet fuel and heating oil	Floats			
Petrol	Floats			
Vegetable and animal oil	Floats			
Oil used for propulsion of the ship				
IFO 380 and 180	Floats, possibly sub-surface			
Diesel	Floats			

5.5 Chemical compounds selected for modelling

Only chemicals transported as cargo are considered. Chemicals required for operation and maintenance of the ship are not modelled as they only constitute an insignificant risk to the environment.

Chemicals may be carried in bulk or in packaged form. Ships may be bulk carriers, specialised chemical tank vessels, container ships or general cargo ships. Further chemicals may be transported on board ferries, Ro-Ro ships etc.

5.5.1 Chemicals in bulk

Modelling of vessels carrying chemicals in bulk is done combining information from port data and VTS data on one hand and AIS data and ship register data on the other hand.

The table below is an example of amounts carried in Danish waters for a period of 1 year. The chemicals are grouped according to physical behaviour when spilled in water and considering other hazardous properties.

Table 5.3 Bulk chemicals transported in the Baltic Sea (BRISK I, 2011)a

Behaviour when spilt in sea water	Environment	Health	Fire	Poland[1]	Entrances of the Baltic Sea (SHIPPOS)
Evaporates				-	10.0 %
Floats				-	-
				-	-
				-	-
				-	1.6 %
				-	-
				-	0.2 %
Dissolves	XA			-	0.3 %
	XB			-	0.5 %
				45.6 %	31.5 %
				41.2 %	54.1 %
Sinks				13.2 %	0.4 %
				-	0.1 %
				-	1.3 %
Total				*100 %*	*100 %*
Total (million tonnes/year)				*1.9*	*34.9*

Table 5.4 Representative hazardous chemicals transported as cargo

Hazardous substance	Behaviour in case of a spill to the sea
Benzene	Floats
Toluene	Floats
Acetone cyanohydrine	Soluble
Acrylonitrile	Soluble
Methyl tert-butyl ether	Soluble
Tar	Sinks
Molasses	Sinks

5.5.2 Chemicals carried in packaged form

The information available on the dangerous chemicals transported to/from harbours only includes limited information on amounts. Information is gained by combining data from HazMat or a comparable national data base and AIS data from the most important harbours. This yields percentages of ships carrying dangerous goods distributed on ship type indicated in the table below.

Lists of the chemicals carried most frequently to/from harbours are prepared indicating behaviour when spilled to the sea as well as ranking of hazardous properties.

In the specific case of the Danish waters only very few chemicals classified as Very Hazardous (red) to the environment are identified. In general the hazard picture for chemicals carried in packaged form is much different from the picture of chemicals carried in bulk. This is in agreement with international studies. Whether this situation equally applies to the other HELCOM countries needs to be verified separately for each country.

It is assumed that the transit transport of packaged dangerous chemicals is of the same nature as the dangerous chemicals transported to/from harbours.

Table 5.5 Percentage of vessels carrying hazardous goods in packaged form (example from the Danish EEZ)

Type of ship carrying dangerous goods	Percentage carrying dangerous goods
Specialised construction vessels	0
Car carriers	0
Container vessels	36.6
Fishing vessels	0
Ferries	0
Ferries/RO-RO	14.4
Cruise ships	0
Refrigerated cargo ships	0
Nuclear fuel carriers	-
Offshore supply vessels	24.8
RO-RO	25.9
Tug boats	0.4
General cargo carriers	6.1
Navy	-

5.5.3 Modelling of chemicals

The assessment of the risk to the environment is made considering chemicals transported in bulk. These chemicals are transported in larger quantities than compounds carried in packaged form.

For the modelling the compounds most hazardous to the environment and transported in bulk are selected. In this way the modelling of the chemicals carried in packaged form is likely to overestimate the risk to the environment in case of a spill.

Chemicals carried in packaged form are distributed evenly on the ship traffic in all waters considering individual types of ship. Percentages are set according to Table 5-1.

The model considers the following classes of chemical (examples are indicated).

Evaporates:

- None

Chemicals evaporating are not considered as they are judged to have no impact on the marine environment.

Floats:

- Hazardous to the environment (yellow) and restricted combat (red in both health and fire hazard): Benzene
- Hazardous to the environment (yellow) and restricted combat (red in fire hazard): Toluene.

Specific chemicals floating sub surface were not identified for Danish waters and consequently they are not modelled.

During combat the personnel of the emergency forces may become exposed to hazards due to the nature of the spill. Safeguarding the personnel may affect the efficiency of the efforts and restrict the operation.

Soluble:

- Very Hazardous to the environment (red), MARPOL class XA: Acetone cyanohydrine
- Very Hazardous to the environment (red), MARPOL class XB: Acrylonitrile
- Hazardous to the environment (yellow): MTBE Methyl tert-butyl ether

Chemicals reacting with water forming water soluble compounds are modelled as soluble.

Sinks:

- Very Hazardous to the environment (red): Tar
- Hazardous to the environment (yellow): Molasses

5.6 Modelling of transport of oil and chemicals

Modelling of the transport of oil and chemicals on cargo type, cargo size and route follows the procedure indicated below.

Modelling of the ship traffic is based on the approach described in Chapter 4.

For each sea area – as defined in Section 4.5 – and each direction (ingoing and outgoing) the basic distribution of bulk cargo types depending on vessel type and size is established separately (compare discussion in Section 4.6, Flow of goods). This task is accomplished in two successive steps:

1. For ports and control lines (VTS centre reporting lines etc.) where goods transport data are available, a distribution of bulk cargoes on type and size is established.
2. Then data is extrapolated to cover the remaining sea areas based on similarities and overlayering of shipping routes. As an example, many ships going to and from ports in the eastern part of the Baltic Sea will create a flow of transportation in the western part of the Baltic Sea on their way to and from the North Sea.

Based on the distribution of cargo and on ship traffic information, the total transported amount of the respective compounds is estimated. Results are validated against information on the total amounts transported.

6 Vulnerable areas and classification of vulnerability and damage

6.1 Method for establishing vulnerability maps

To describe environmental vulnerability, a number of environmental parameters are mapped for each of the six seasons. The environmental parameters are selected in such a way that the most critical parameter receives a higher weight than the others.

In this report the vulnerability of the marine environment is defined towards oil on the sea surface, dissolved chemicals in the water phase and towards chemicals on the sea floor.

Vulnerability is assessed for each season, since the vulnerability is qualitatively different for each season. The following definitions are used for the seasons:

Winter, no ice: Dec
Winter, ice: Jan, Feb
Spring, ice: Mar
Spring, no ice: Apr, May
Summer: Jun, Jul, Aug
Autumn: Sep, Oct, Nov

The list of relevant environmental parameters comprises quantities that traditionally are difficult to compare. They include parameters such as international protection areas, foraging areas of migratory birds, breeding areas of fish, areas with aquaculture (e.g. fish farming), fishing grounds, archipelagos, wadden seas, shallow water areas, bathing beaches, cities and rocky shores. Foraging areas and breeding areas are only vulnerable on certain seasons and therefore maps are developed for each season.

Further, the following issues are included in the vulnerability assessment:

- risk for environmental damage during clean-up operation,
- regeneration of affected organisms and the affected areas.

The following indicators were used for BRISK I:

1 Rocky shores and stone reefs

2 Estuaries

3 Coastal lagoons

4 Shallow inlets and bays

5 Underwater sand banks (on shallow water < 10 m)

6 Sandy beaches (general)

7 Seagrass meadows

8 Spawning area on shallow water for fish with demersal eggs

9 Nursery areas for fish on shallow water (< 10 m)

10 Offshore spawning areas for fish with pelagic eggs (i.e. mainly cod and sprat)

11 Wintering areas for sea and shore birds

12 Staging areas for migrating sea and shore birds

13 Breeding areas for sea and shore birds

14 Moulting areas for sea birds See above

15 Marine mammals (breeding and haul out site for seals)

16 Protected areas

17 Aquaculture

It is noted that, at this stage, the environmental vulnerability in this case primarily comprises parameters traditionally thought of as '"environmental". However, this initial list of parameters may be extended to incorporate other relevant environmental or socio-economic indicators as the project progresses. The decision regarding how this list needs to be modified and/or extended will be finalized during a later stage of the BRISK II project (specifically, in Task 3.4 Environmental Vulnerability Mapping).

Every parameter receives a weight according to its vulnerability. The weighing is carried out according to a transparent system that easily can be changed and thereby be adjusted to changed prioritisation by society. The weighing of vulnerability is carried out based on the judgement of experienced marine biologists and it is planned to be discussed among several experts.

Table 6.1 shows the weighing matrix from BRISK I for illustration purposes. Note, that two separate groups of experts came up with two weighing alternatives. Based on the resulting vulnerability maps, no significant difference could be observed. For BRISK II, the weighing matrix will need to be updated as part of Task 3.4 *Environmental Vulnerability Mapping*. It will be discussed whether one parameter weighing matrix is sufficient or whether a sensitivity analysis similar to BRISK I will be carried out.

Table 6.1 *Weighing matrix for environmental vulnerability. The seasonal vulnerability score (from 0 to 4) is multiplied with the overall score in the fifth column (from 1 to 10).*

Nr	Environmental Parameters	Seasonal weighting				The fifth column. Suggestions on extra scores (between 0-10)	
		Winter	Spring	Summer	Fall	Alternative 1	Alternative 2
1	Rocky shores and stone reefs	4	4	4	4	10	3
2	Estuaries	2	4	4	4	9	3
3	Coastal lagoons	2	4	4	3	10	3
4	Shallow inlets and bays	2	4	4	3	8	2
5	Underwater sand banks (on shallow water <10 m)	2	3	3	3	5	1
6	Sandy beaches (general)	1	1	2	1	7	2
7	Seagrass meadows	3	4	4	3	10	3
8	Spawning area on shallow water for fish with demersal eggs	3	4	4	3	3	10
9	Nursery areas for fish on shallow water (<10m)	3	4	4	3	3	10
10	Offshore spawning areas for fish with pelagic eggs (i.e mainly cod and sprat)	0	1	2	1	1	6
11	Wintering areas for sea and shore birds	4	3	0	2	3	10
12	Staging areas for migrating sea and shore birds	2	4	2	4	3	10
13	Breeding areas for sea and shore birds	2	4	4	1	3	10
14	Moulting areas for sea birds	0	0	4	0	3	10
15	Marine mammals (breeding and haul out site for seals	3	3	3	2	3	9
16	Protected areas	4	4	4	4	5	5
17	Aqua culture	4	4	4	4	5	5

6.2 Examples of environmental vulnerability maps

This section shows maps of the resulting environmental vulnerability. Vulnerability is shown as a function of different impacts (i.e. oil on sea surface, dissolved chemicals in the water phase, chemicals on the sea floor) and of different season. The objective of the maps is to serve as a basis for the calculation of the likely environmental damage in each grid cell in the different spill scenarios.

Furthermore, the maps give an intuitive understanding of the distribution of vulnerability and the maps can therefore also be used in specific oil spill response situations.

The weighing is given in the weigh matrix in Table 6.1.

Note that BRISK I only dealt with vulnerability towards oil. BRISK II will also address vulnerability towards chemicals. Based on the considerations described in section 5.5.3, the relevant classes are soluble chemicals and sinking chemicals.

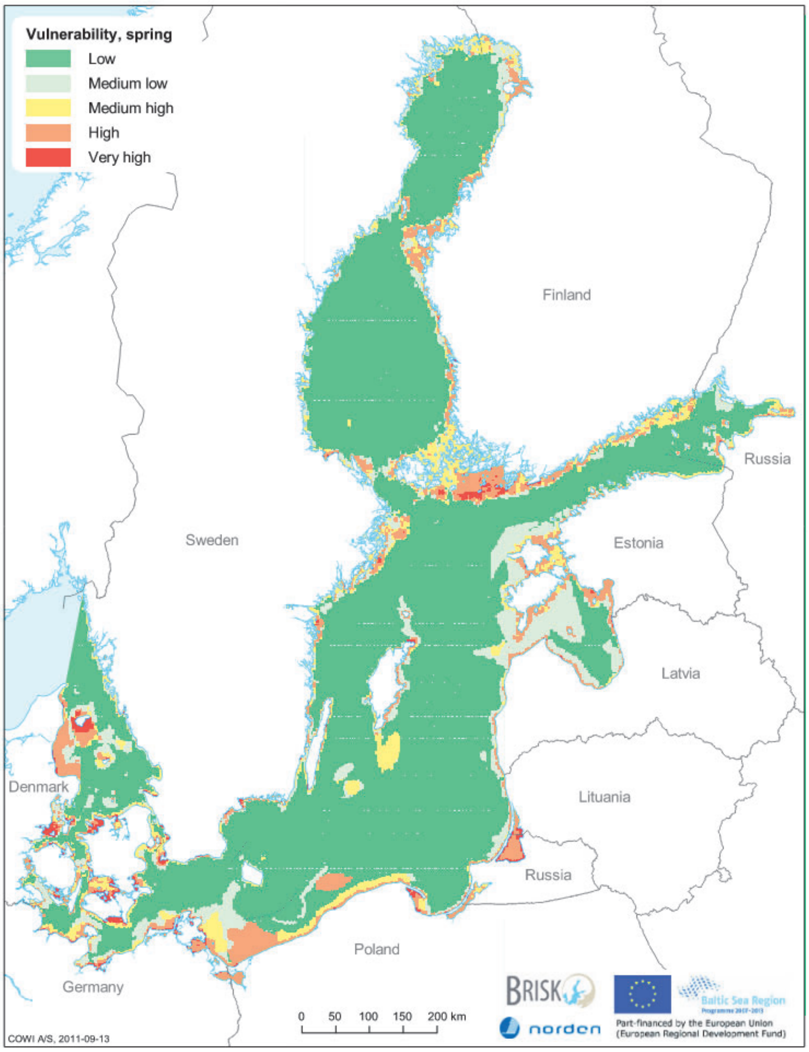


Figure 6.1 Example: Vulnerability map towards oil for spring season from BRISK I (BRISK I, 2011).

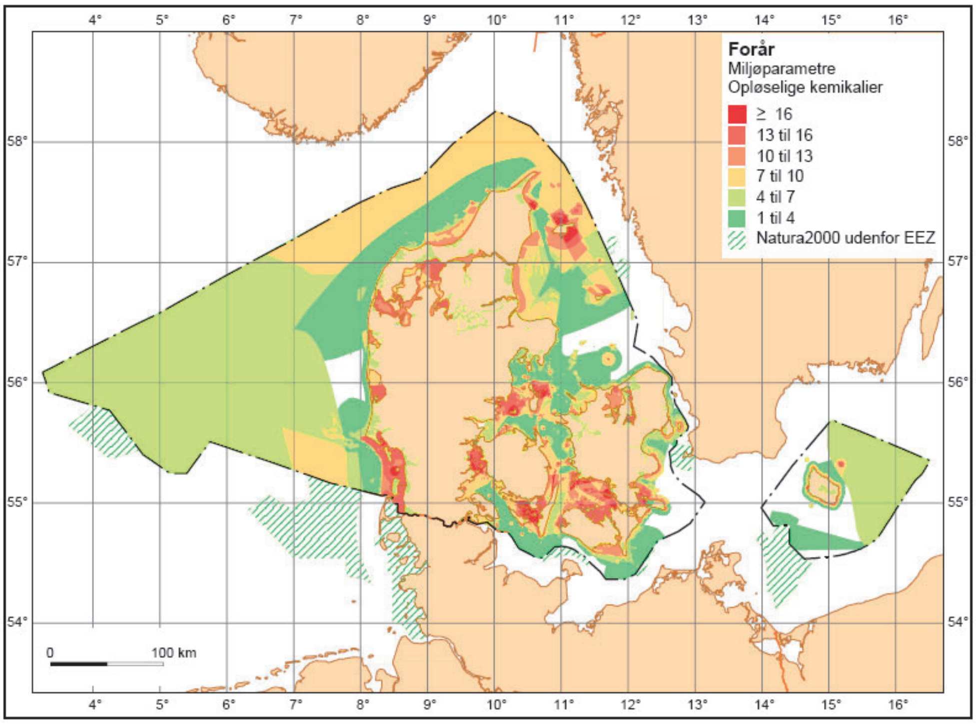


Figure 6.2 *Example: Vulnerability map towards dissolved chemicals for spring season from (Oil spill DK, 2007) (Note: Vulnerability towards dissolved chemicals was not investigated during BRISK I)*

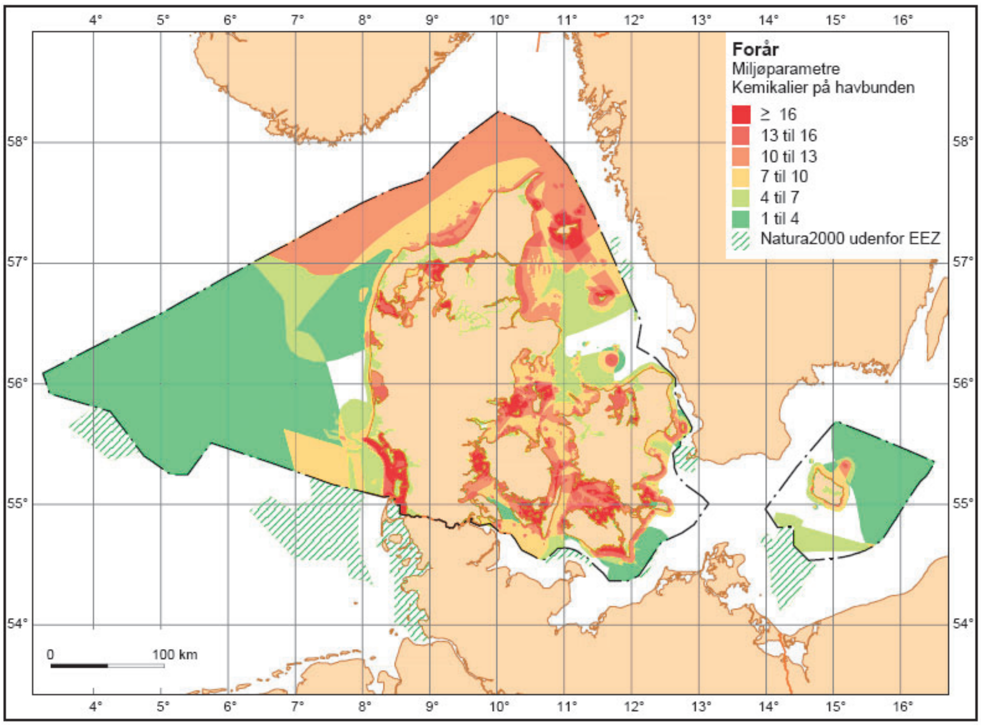


Figure 6.3 *Example: Vulnerability map towards chemicals on the sea floor for spring season from (Oil spill DK, 2007) (Note: Vulnerability towards chemicals on the sea floor was not investigated during BRISK I)*

6.3 Damage to the marine environment

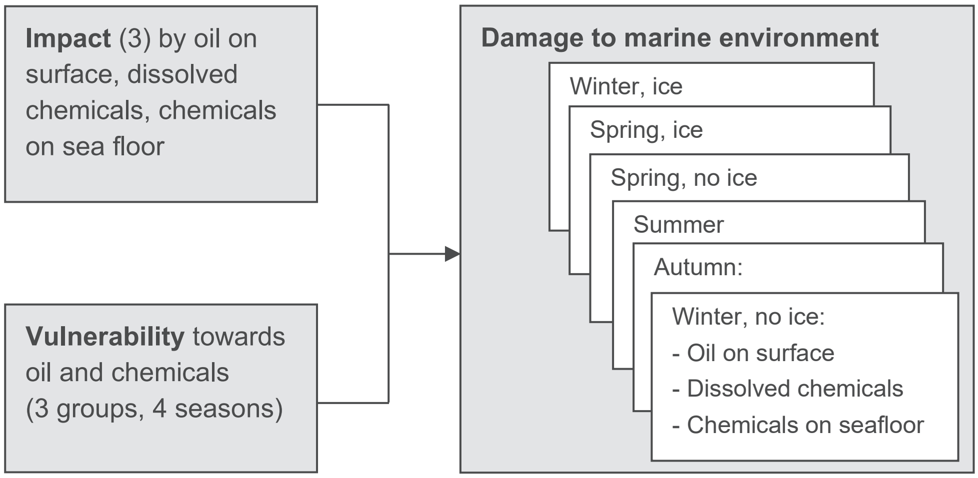


Figure 6.4 Sketch for assessment of environmental damage

The goal of the vulnerability quantification is to illustrate the geographical distribution under different assumptions and to apply this in the calculation of the environmental damage. Since there is no unambiguous definition of environmental damage, this project will establish its own specific definition based on the project's particular requirements, which is explained below.

The definitions applied above result in an index ranging between 0 and 20 which again is integrated into 6 classes with different colours in the plot.

The term impact implies physical properties:

- Average amount of kg oil per area (map)
- Frequency of impact by chemicals per area (map)
- Frequency of chemicals on the seafloor per area (map)
- Amount of oil that hits the coast per time (number) (Environmental consequences of stranded oil is not included in this study)

The first 3 impacts can be related to vulnerability to determine an expression for environmental damage.

Environmental damage is in the following defined as the product between the impact on a specific area and the vulnerability of the area. The calculated value as such is a hybrid number since it contains the subjective but transparent and systematically developed vulnerability. The damage shall be looked upon as an index for relative and comparative analysis (change of traffic pattern, enhanced response action, etc.).

7 Frequency and quantity of oil and hazardous substance spillage

7.1 Ship accidents in the Baltic Sea

In a first step, it needs to be clarified, which types of ship accidents are to be modelled. For BRISK I, the accident statistics over a period of five years was used as a basis. From this data set a number of entries were dropped:

- All accidents involving vessels of less than 300 GT (compare Chapter 3)
- Accidents in harbours (compare Chapter 3)

The resulting statistics are summarised in Table 7.1.

Table 7.1 Total number of sea accidents in the BRISK area 2004-2008 (BRISK I, 2011) (HELCOM database plus national corrections, only relevant accident types, without port accidents)

Accident type	DE	DK	EE	FI	LT	LV	PL	RU	SE	Total
Grounding	3	110	5	30		5	3	10	64	230
Collision with vessel[1]	2	8	2	4	2	2	3	2	6	31
Collisions with object	3	5		2				3	10	23
Fire	2	10	2	2		2			16	34
Physical damage		1								1
Pollution					1			1	4	6
Foundering								1	1	2
Total	*10*	*134*	*9*	*38*	*3*	*9*	*6*	*17*	*101*	*327*

7.2 General modelling

7.2.1 Fujii's model

In the present context, a model is understood to be a calculation method permitting to estimate the occurrence of sea accidents based on basic data. The present section describes how accident frequencies are calculated by means of the

[1] Only ship-ship collisions, where both vessels have at least 300 gross tonnage are considered.

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 calculation the respective factors for each area and accident type. The aim is to describe the factors such that they describe the actual situation as good as possible. It is in the nature of such a calculation that it will always be an uncertain approximation. 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 surveillance)

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). The latter adjustment will influence Fujii's *N* parameter (e.g. by means of altered traffic distributions).

Fujii's model is used to calculate the occurrence of sea 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. 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:

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

Other parameters such as vessel speed, angles and lengths etc. are equally part of the calculation of the collision frequency (see Section 7.3 for a general overview).

The risk analysis of oil and hazardous chemical 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 (today, 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(Ni) × Pg × Pc × Ps × Pe

7.2.2 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{sea accident} ×

P{hull damage with possibility for spillage | sea 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{sea accident} is the frequency that a sea accident that can cause spillage occurs. This quantity includes the effect of the traffic intensity (*N, N1* 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 condi- tions (P_c in Fujii's model).

P{hull damage with possibility for spillage | *sea accident}* is the probabil-ity of a sea accident entailing a damage that breaks the containment of oil or hazardous substances and therefore can lead to an accident. Thus, it in-cludes aspects of Fujii's factor P_S. However, this differentiation is neces-sary, since the risk analysis shall be capable of handling the size of the spills.

P{spill size | *hull damage with possibility for spillage}* is the probability of a given spill size given 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 (today, 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 | *sea accident}*

and

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

as random distributions in stead 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.

7.2.3 Calculation procedure

As a consequence, the calculation of the spill frequencies are calculated on the basis of a traffic model that reflects the distribution of the ships with respect to

- vessel type
- vessel size
- hull configuration (single/double)
- load state (loaded/in ballast)
- draught
- operational vessel speed
- risk-reducing measures (RRMs)

The traffic model is prepared for traffic corresponding to the traffic today and in 2036.

The models for the frequency of sea accidents include the effect of following RRMs:

- Pilotage
- Ferry (similar effect as pilotage due to local experience and high standards)
- Systematic calls to vessels falling under the pilotage recommendation
- VTS centres
- Increased surveillance
- Double hull at the cargo tank (implemented as part of the consequence model)
- Double hull at the bunker (implemented as part of the consequence model)
- ECDIS (grounding) – The recent decisions by IMO on phase-in carriage requirements for ECDIS are to be taken into account
- Bridge alarm
- Alcohol ban enforcement

- Ice training for navigators
- Traffic separation schemes
- Escort towing in narrow shipping lanes
- Emergency towing of damaged ships
- Usage of international reporting systems
- Regular emergency exercises with different types of vessels (to be implemented as part of the emergency response model)

Other effects may in fact *increase* the risk of accidents. They can be considered in the same way as RRMs. However, while RRMs are modelled by a factor ranging between 0 and 1, risk-increasing measures or circumstances are modelled by a factor exceeding 1. In the BRISK model, this includes the following effect:

- Close distance between ships in ice-breaker convoys
- Ship is part of the shadow fleet (lower standards)

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

Once the calculated spill frequencies have been obtained, the spill frequencies per substance group are calculated based on the relative distribution of the transported cargo (compare Sections 4.6 and 5.6).

7.3 Modelling of accidents at sea

7.3.1 Grounding

Probability of grounding

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

1. The Baltic Sea is divided into several areas (Section 4.5).
2. For each sea 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 waterway section has a different frequency.
3. The grounding frequency is corrected for the effect of pilotage, such that a pilot-free frequency is obtained.

4 Present and future grounding frequency on an annual basis is calculated by multiplying the distance sailed by different ships with the grounding rate per nautical mile. This step is performed separately for piloted and non-piloted ships. In the former case, the result is multiplied with a risk reduction factor for having a pilot on board.

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 (see Section 4.4). In addition, it needs to be investigated, whether there is a principal difference between the ice season and the ice-free season as far as grounding frequencies per sea mile are concerned.

Probability of spill given 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

The used probabilities of cargo spill given grounding are indicated in Table 7-2 below. The numbers indicated for groundings on soft ground are derived from statistics for both soft and rocky grounds. However, the earlier Danish analysis showed these numbers to predict the situation for the prevailingly soft grounds in Denmark with good precision. For the case of rocky grounds, modelling is based study on a study that was performed at Aalto University (Ylitalo et al., 2010) as part of the BRISK I project.

Table 7.2 Probability of cargo spill given 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

The used probabilities of bunker spill given grounding are indicated in Table 7-3 below.

Table 7.3 Probability of bunker spill given grounding

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, which ever 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 7.4.

Table 7.4 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 future regulations for double-hull at bunker tanks 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 lubricants are assumed to be bunker oil.

For general cargo and Ro-Ro ships including Ro-Pax ferries, which are not double-hulled at the bunker tanks the following two scenarios are used:

Scenario 1:
Spill of 0-$^1/_6$ of the bunker capacity: *P{scenario 1 | spill}* = 0.95

Scenario 2:
Spill of ½-1 of the bunker capacity: *P{scenario 2 | spill}* = 0.05

Spill between $^1/_6$ and ½ is considered not very probable and therefore not modelled in a separate scenario.

Oil and chemical tankers, bulk carriers and container ships are double-hulled next to the bunker tanks already today. For them, the following scenarios are assumed to apply:

Scenario 1:
Spill of 0-$^1/_{200}$ of the bunker capacity: *P{scenario 1 | spill}* = 0.875
(corresponding to a leakage of the lubricant tanks)

Scenario 2:
Spill of $^1/_{200}$-$^1/_6$ of the bunker capacity: *P{scenario 2 | spill}* = 0.11875

Scenario 3:
Spill of ½-1 of the bunker capacity: *P{scenario 3 | spill}* = 0.00625

7.3.2 Ship-ship collision

The collision modelling is based on the route-based traffic analysis described in Chapter 4.

Frequency of route collisions

Collision frequencies for route collisions are modelled for two situations (Figure 7.1):

› head-on collisions between ships sailing in opposite directions

› overtaking collision between ships sailing in the same direction

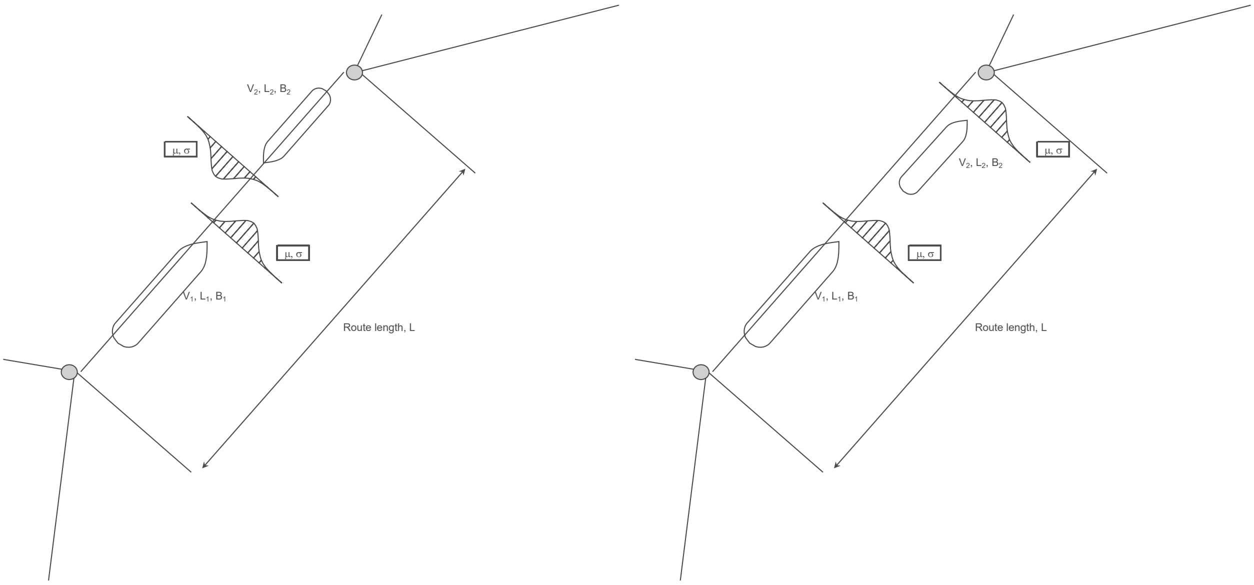


Figure 7.1 Head-on and overtaking collisions

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

With the detailed route and traffic description described in Chapter 4 it is possible to calculate the collision frequencies for the respective route segments.

Frequency of node collisions

The frequencies of node collisions are modelled for a number of relative manoeuvres between the crossing ships. Figure 7.2 shows four important crossing manoeuvres.

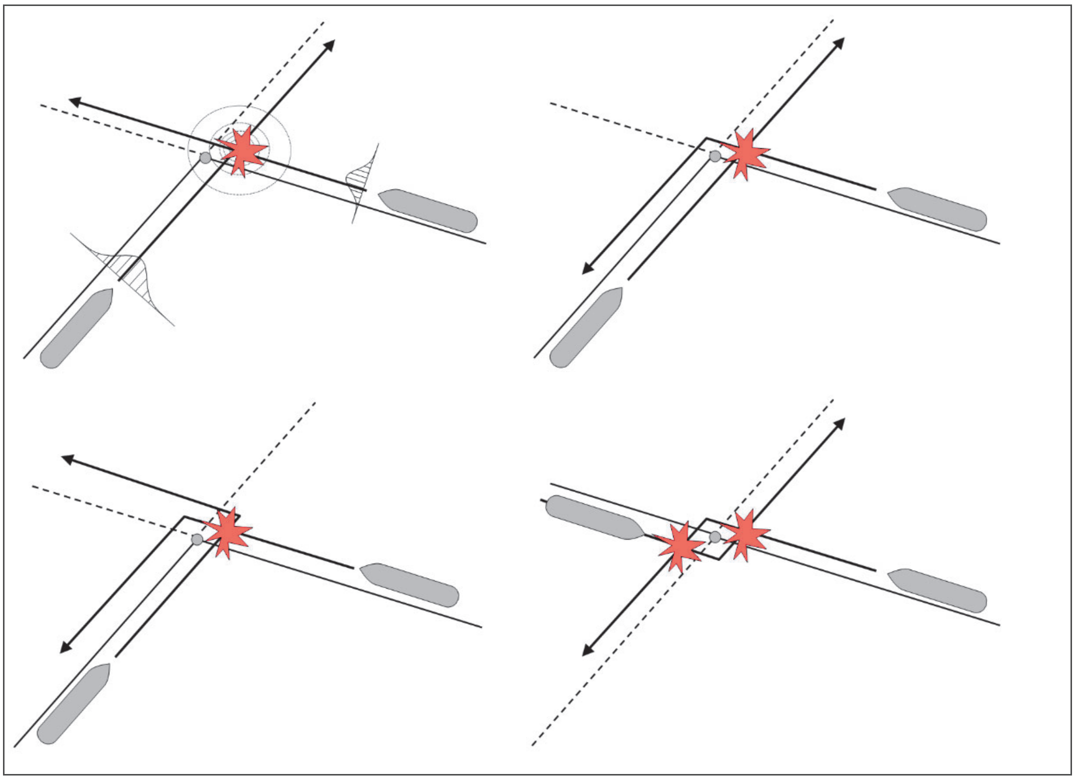


Figure 7.2 Regular crossing collisions and bending/crossing collisions

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

Based on the detailed traffic description described in Chapter 4 it is possible to calculate the collision frequencies for the respective nodes in the route net.

The effect of sea ice upon node and route collision frequencies

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 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 Section 4.4). Finally, the short distances between the ships sailing in an ice breaker convoys equally have an effect (Section 7.2.3).

Hull damage in case of collision

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 Technical University of Denmark, who elaborated routines simulating large numbers of representative collision scenarios. A neural network is applied to

› determine the penetration at the hit vessel (both for bulb-shaped and conventional ship bows)

› the damage length at the hit vessel

› the damage height at the hit 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.

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:

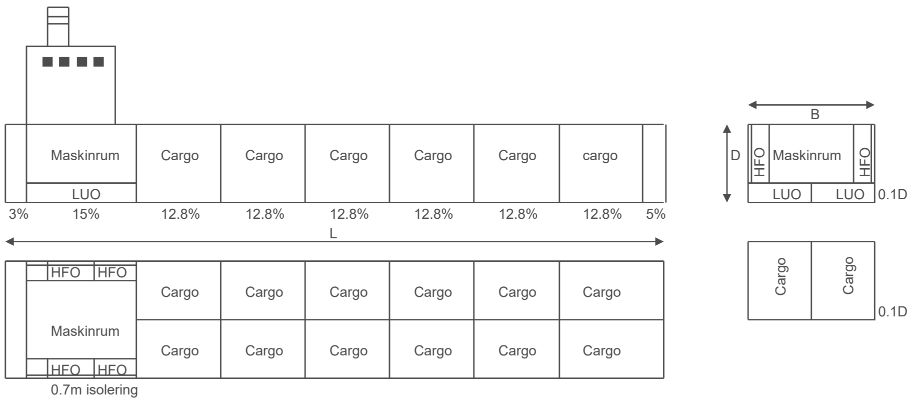
› The ships are categorised into seven ship types
- tankers with single and double hull
- chemical tankers
- bulk carriers
- container ships
- general cargo ships / packed goods
- Ro-Ro ships
- Ro-Pax ferries

› Size of the bunker tank

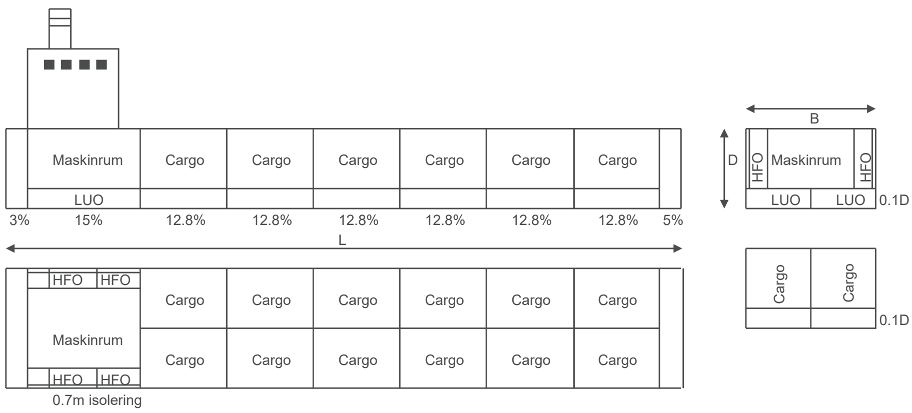
› Division into cargo compartments of equal size

- 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°
- Ship types are represented by rectangular boxes with rectangular cargo compartments, i.e. as idealised vessels (Figure 7.3 illustrates the case of tank ships):

Single hull



Single hull with double bottom



Double hull

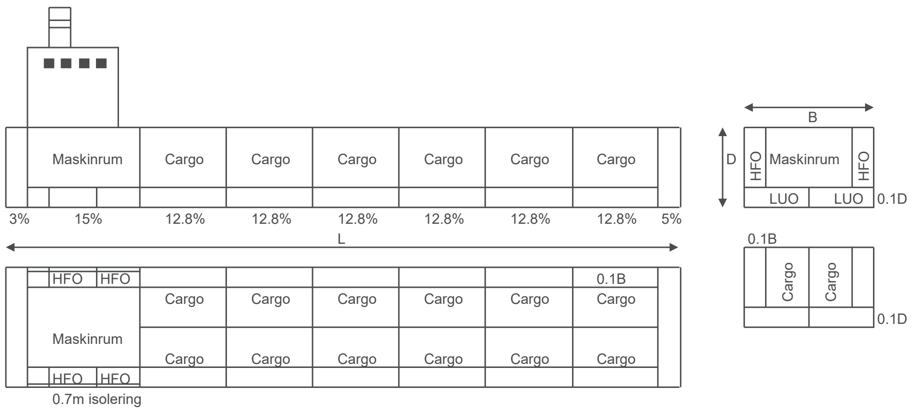


Figure 7.3 Idealised tankers used for determining the spill in case of hull damage

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

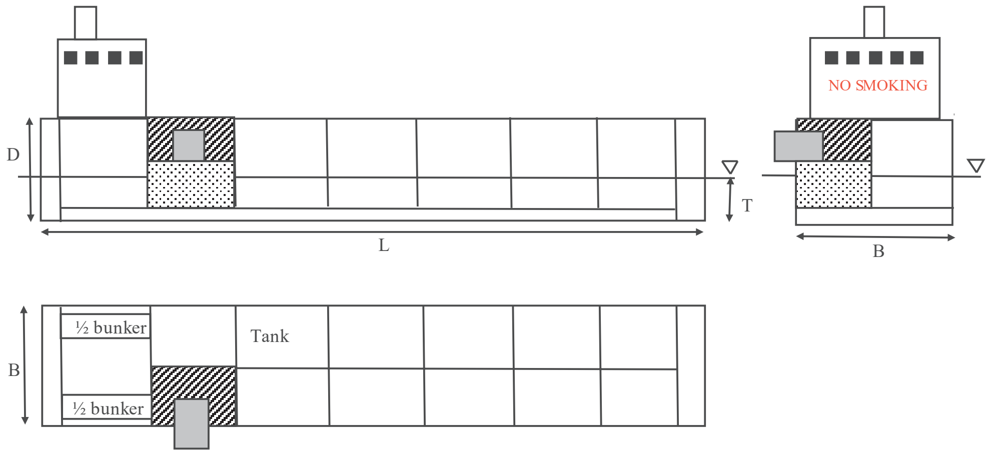


Figure 7.4 Example of a penetration above the water line. Det shaded part is leaked. The dotted part remains in the tank.

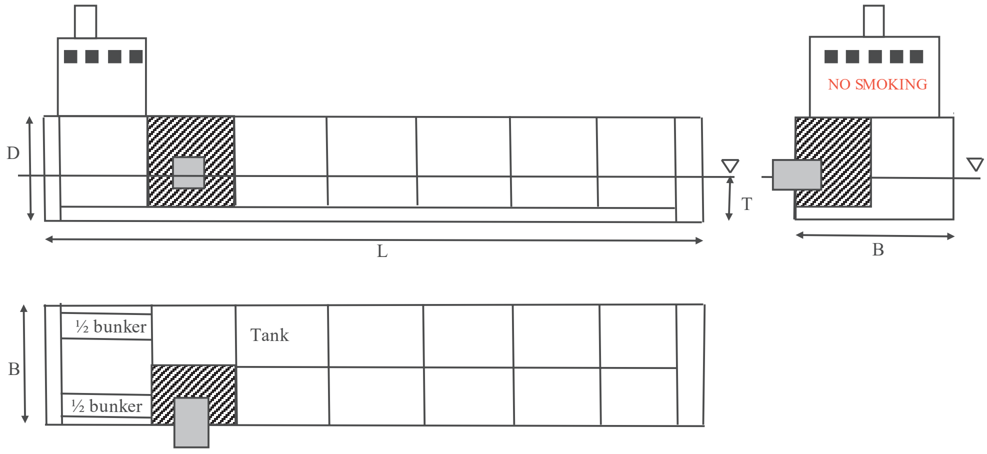


Figure 7.5 *Example of a penetration below the water line. The entire shaded part is leaked.*

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 stored in the intervals indicated in Table 7.5. For each interval, a probability is indicated.

Table 7.5 *Relative spill intervals for which the respective probabilities are calculated in the simulation*

Cargo spill size classes	Bunker spill size classes
[0-1/1000] (no spillage)	[0-1/1000] (no spillage)
]1/1000-1/18]	]1/1000-1/6]
]1/18-1/9]	]1/6-1/4]
]1/9-1/6]	]1/4-1/3]
]1/6-1/3]	]1/3-1/2]
]1/3-1/2]	]1/2-1]
]1/2-1]	

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

- the impacting ship is
  - loaded/not loaded
  - hitting diagonally from the front/back
- the hit 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 yield a very large number of combinations (>100,000). The results are stored in a database table.

7.3.3 Fire and explosion

Based on an investigation by DNV (DNV, 2003), the following probability of fire/explosion with environmental consequences is used:

P{Fire on a tank ship cargo compartment} = 1.5 × 10^{-8} / sailed nautical mile with loaded tank ships

In BRISK I, (BRISK I, 2011), it was assumed that 60 % of all tank ships are loaded. Furthermore,

P{Spill | fire on a tank ship} = 1.0

The relationship between probabilities and relative spill sizes is indicated in Table 7.6.

Table 7.6 Probabilities of the relative spill sizes in case of fire aboard a tanker

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

7.3.4 Foundering and other potentially polluting accidents

Other accidents than those described above can also be the cause of a spillage. During 2004-2008, seven such accidents have been recorded (BRISK I, 2011). They included four cases of pollution, two cases of foundering and one case of physical damage. The causes have not been specified for any of these events. Considering that the causes are not to be sought with collisions, groundings or fires, the typical causes to be expected are hard weather conditions, structural fatigue and shift of cargo.Frequency

Frequency

Two foundering events during 2004-2008 correspond to 0.4 occurrences per year. With regard to the yearly traffic 61.5 million nautical miles sailed in 2008/2009, this corresponds to 6.5 × 10^{-9} occurrences per nautical mile. This numbers needs to be updated as part of BRISK II.

Consequences

The probability of spill given 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)*

7.4 Deliberate and inadvertent spills

7.4.1 Introduction

Deliberate and inadvertent oil spills from ships are the most frequent spill source. However, most spills are either very small or consisting 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 deliberate and inadvertent oil spill is modelled based on statistical experience with such spills.

In the case of Denmark, no examples of deliberate or inadvertent spill of other hazardous substances than oil from ships are known and it is presumed that such spills do not play a significant role in other HELCOM countries' EEZs. Besides, Chapter 3 concludes that there is no necessity for other modelling hazardous substance spills than oil.

7.4.2 Data sources

Every year, HELCOM registers the number and size of spills reported by the member countries. These registrations are solely based on surveillance flights.

Table 7.7 illustrates the situation observed during 2005-2009.

Table 7.7 Oil spill observations during aerial surveillance in the HELCOM area 2005-2009

Size	DE	DK	EE	FI	LT	LV	PL	RU	SE	Total
< 1 m^3	14.8	27.6	27.4	23.6	0	2.6	14.2	0.4	61.4	172.0
1-15 m^3	0.8	2.2	6.6	1.2	0	0	0.2	0	2.4	12.2
15-300 m^3	0	0	0.8	0	0	0	0	0	0.4	2.2
> 300 m^3	0	0	0	0	0	0	0	0	0	0
Unknown	8.8	7.2	1.0	1.8	0	0	0	0	6.4	25.2
Total	24.4	37.0	35.8	26.6	0	2.6	14.4	0.4	70.6	211.8
Total per million sailed miles	*4.4*	*2.7*	*7.1*	*3.7*	*0*	*1.2*	*5.7*	*1.3*	*3.3*	*3.5*

The actual number of spills is higher than observed number. This applies especially to comparatively volatile oil types, where the time to evaporation is shorter than the interval between to successive surveillance flights. However, these volatile oil types can typically not be fought by emergency response for the same reason, i.e. their quick evaporation. More heavy oils, on the other hand, remain present during an extended period of time and are almost always detected. Thus, it is permissible in the present context to assume that the number of observed spills equals the number of actual spills.

7.4.3 Classification 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.

During BRISK I, a universal size distribution is used, as indicated in Table 7.8. This has the advantage of permitting a realistic estimate for those countries, where the number of observations and therefore the possibility of meaningful statistical conclusions are limited.

In Table 7.8 it has been assumed that events with unknown spill size (11.9 % 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 respective coast guard authority. There have not been observed any illegal releases of 300 m^3 or above.

Table 7.8 Probability of the respective spill sizes in the HELCOM area, 2004-2005

Spill size	<1 m^3	1-15 m^3	15-300 m^3	>300 m^3
Probability	81.4 %	7.4 %	2.3 %	0.8 %

Oil types and type distribution

In BRISK I (BRISK I, 2011) mineral oil was divided into two types: A light, highly volatile types represented by diesel and a heavy, little volatile type represented by IFO 380. In the Danish case, diesel dominated with 88.4 % of all observations, whereas IFO 380 contributed only 11.6 %.

If the national databases contain the necessary information, a new distribution for the entire Baltic can be established. Else, a rough estimate based on the Danish experience will be made.

In addition, it is necessary to establish the current and future expected shares of new oil types such as low-sulphur oils and co-processed oils, cf. section 3.3.2.

7.4.4 Spill from accidents with small ships

Oil spill databases contain not only deliberate and inadvertent spills but equally events due to ship accidents modelled in Section 7.3. As far as ships with 300 GT and more are concerned, the corresponding events are simply filtered out and ignored.

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. In the case of Denmark it turned out that oil spills due to ship accidents exclusively involving ships below 300 GT correspond to 3 % of the volume of deliberate and inadvertent spills. As a consequence, the risk from accidents with small ships was not included in the earlier Danish analysis (Oil spill DK, 2007) nor in BRISK I (BRISK I, 2011). It is proposed to proceed accordingly in the present analysis.

7.5 STS operations and bunkering at sea

STS operations (ship-to-ship transfer) and bunkering at sea resemble each other in most aspects: One vessel is anchored, another vessel arrives, berths, a hose connection is established, and oil is transferred from one vessel to the other.

Bunkering in harbours is not part of the scope (compare Chapter 3).

In Section 3.3.8 and 3.3.9, two main scenarios have been identified:

- Accidents during transfer, e.g. hose failure, overbunkering etc.
- Collisions during approach, i.e. the arriving vessel hits the anchored vessel, leading to hull penetration and spillage

Compared to ship-ship collisions and groundings, the spill risk contribution of these events is relatively limited. A comprehensive study on these scenarios was carried out for BRISK I (cf. Appendix 4 to Model Report Part 4 - Frequency and quantity of spill of oil and hazardous substances). This study will be revisited and – where necessary – amended as part of BRISK II.

7.6 Offshore oil and gas activities

If a ship hits an offshore installation, oil can leak both from the installation and from the involved ship.

Potentially involved vessels can be divided into two groups:

- Dedicated vessels, i.e. vessels bound to or from the affected installations
- Passing vessels, i.e. traffic that is in no way related to the affected offshore installations

In the case of Denmark, all offshore installations are located in the North Sea, i.e. outside the Danish part of the HELCOM area. However, oil platforms may exist in other parts of the Baltic Sea.

7.6.1 Dedicated vessels

Collision frequency

Collisions between dedicated vessels and offshore installations occur several times a year in most countries, where such installations are operated. Therefore, there is a good statistical basis for estimating the yearly collision frequency. If this is corrected for the number of dedicated vessel visits, a general collision probability per visit is obtained. This allows estimating the yearly collision frequency for a specific platform with a specific number of visits per year.

It should be noted that most collision occur at a low speed and do not cause much damage.

Probability of bunker leakage

Dedicated vessels can generally hit offshore installations in three main modes:

- During manoeuvring, i.e. while the vessel is slowly moving towards the offloading position, where it can be reached by the cranes on the installation
- During positioning, i.e. while the vessel is using its controls to maintain a stable position under the crane
- Due to random movements, e.g. because of power or steering outage or other causes

In general, only the last impact mode, i.e. impact due to random movements, potentially involves sufficiently much energy to cause a leakage from the vessel bunker. Only 10 % of all collisions at most are of this type.

Out of all random movement impacts, only a small number will actually be violent enough to cause severe damage. This fraction was estimated as 1 % in 'Oil spill DK' (2007) and BRISK I (BRISK I, 2011).

Finally, the length of the bunker tank is only 15 % of the total ship length. As a consequence, it was conservatively estimated to estimate the probability that the damage involves the bunker tank as 25 %.

As a consequence, the probability of bunker spill given collision evolves as $P = 0.1 \times 0.01 \times 0.25 = 2.5 \times 10^{-4}$ for vessels that are involved in offloading procedures. Other dedicated vessels, such as diving support or standby vessels, are not involved in offloading procedures and can only hit an installation in random movement mode. Therefore, the number of collisions is lower, whereas the probability of bunker spill given collision is higher, i.e. $P = 0.01 \times 0.25 = 2.5 \times 10^{-3}$.

7.6.2 Passing vessels

Collision frequency

Accidents of this type are very rare. In the Danish sector of the North Sea, only one single case has been reported up to now. Therefore, statistical methods are only little meaningful. Instead, the AASHTO model (AASHTO, 2007) for ship impact at bridges is modified to estimate the collision frequency. For a given collision candidate, i.e. a given ship sailing on a route next to the offshore installation, the collision probability is modelled as

$$P = P_a \times P_g$$

where

P_a … the aberrancy probability, i.e. the probability that a ship veers off course due to mechanical or human error

P_g … the geometrical probability, i.e. the probability that an aberring ship hits the offshore installation

Probability of leakage

The probability of a major leakage given collision is estimated as $P = 0.01$ (BRISK I, 2011).

7.6.3 Damages to offshore installations

Offshore installations can be damaged due to ship impact as well as to other reasons, which can result in oil spill. The Model report contains details about the way the corresponding spill risk is estimated.

7.7 Collisions with fixed objects

7.7.1 Collisions with large buoys

Collision frequency

The collision frequency is modelled in the same way as for passing ship impact at platforms, see Section 7.6.2

Probability of leakage

Collisions of ships with large buoys resemble ship-ship collisions with the involved ship being in the role of the hitting ship and the buoy being in the role of the hit ship. In most cases, the hitting ship suffers only small damages. However, the situation can be different, if a small ship hits a very large buoy. This case is estimated in a general way and will be compared to statistical evidence, if available.

7.7.2 Collisions with wind farms

Collision frequency

The collision frequency is modelled in the same way as for passing ship impact at platforms, see Section 7.6.2. However, some ships are not able to reach the wind mill foundation because of their draught exceeding the local water depth. These ships will run aground instead and are already covered by the grounding model outlined in Section 7.3.1

Probability of leakage

The probability of leakage given collision with a wind mill foundation is modelled based on a simple estimate.

8 Spreading and containment of spilt oil and hazardous substances

8.1 Introduction

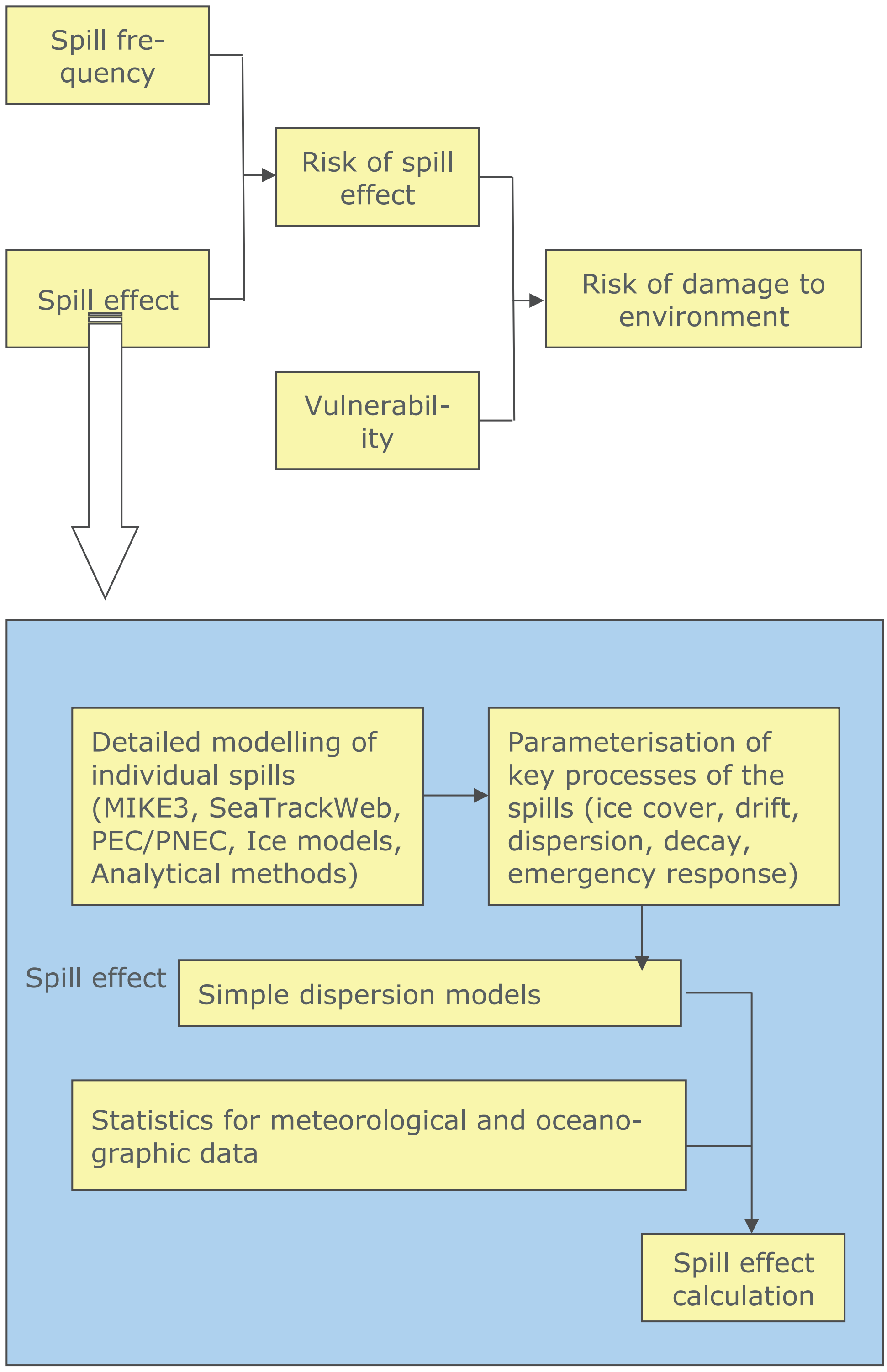
This note describes the proposed methodology for modelling of the impact from oil- and chemical spills in the ocean.

The term 'impact' from oil- and chemical spills to the marine environment is in the present context used to describe the quantity of oil or chemical within the marine environment during a spill event.

The modelling of the impact is carried out by numerical modelling of the transport and dispersion of oil and chemicals onto and within the ocean while subject to degradation and changing characteristics. The effect of the emergency response to the spills is likewise modelled.

The principles of the modelling are shown in the figure below. Detailed modelling of selected individual spill events are carried out using advanced numerical models, supported by analytical calculations. Based on this, key processes are identified and parameterised into simpler models for spill simulations. The advantage of the simpler models is that they enable simulation of a large number of scenarios, which is required for the overall risk assessment.

The purpose of the simulations is to describe the impact in such way, that the result can form the basis for strategic decisions concerning the future development of the emergency response while considering changed and increased ship traffic on one hand, and the effect of future risk reduction on the other hand.


Spill fre-
quency
Risk of spill
effect
Spill effect
Risk of damage to
environment
Vulnerabil-
ity
Detailed modelling of
individual spills
(MIKE3, SeaTrackWeb,
PEC/PNEC, Ice models,
Analytical methods)
Parameterisation of
key processes of the
spills (ice cover, drift,
dispersion, decay,
emergency response)
Spill effect
Simple dispersion models
Statistics for meteorological and oceano-
graphic data
Spill effect
calculation

Separate modelling tools are established for three types of spills:

- Oil and floating chemicals including submerged oil
- Soluble chemicals including chemicals which react and dissolve
- Sinking chemicals

It is proposed to apply 2x2 km grid cells throughout the Baltic Sea for all impact modelling.

Separate modelling is carried out for each of the four seasons. The reason is that the vulnerability varies throughout the year and because the presence of ice significantly changes the dispersion pattern of oil and chemicals.

The following parameters affect both the spreading and dispersion of oil and floating chemicals as well as the emergency response:

- Sea temperature
- Frequency of wind velocity and direction
- Frequency of fog and mist
- The number of hours with daylight

The frequency of wind directions influence further influences the modelling of spill of soluble chemicals.

8.2 Oil and floating chemicals

8.2.1 Introduction

In this section the term 'oil' is used indifferently to describe oil and floating chemicals as the two components are modelled in the same manner.

The detailed processes of transport, dispersion and decay of various oil types on the ocean is parameterised and simplified in such manner that key features of the behaviour are maintained and a simple generic model be established. The advantage of the simple model is that it is able to calculate a large number of calculations. In this regard the modelling is different from traditional oil spill simulations in which advanced process models are applied to describe the effects of a particular oil spill with high accuracy.

Thus, the modelling includes a description of the spreading of the oil on the water surface, the drift by current and wind (with or without ice cover), as well as the decay of the oil. For light oil types, the decay is simplified to describe only the evaporation while for heavy oils the decay is simplified to describe emulsification and natural removal from the surface.

8.2.2 Principles for measurement of impact

The impact of oil pollution is calculated on basis of the generalised descriptions of transport, spreading and decay of oil during the entire spill event. As a result, the following is found:

- The amount of pollution in each calculation cell in the ocean as a function of time
- The total amount of oil hitting the shoreline

1 Offshore

The offshore impact is area specific and consists of the amount of pollution (mass) and the duration (time) of the pollution in the area considered. The term 'impact' in the present context is solely defined on basis of the occurrence of pollutants and time, thus omitting environmental parameters.

The justification for including the *amount* of pollutant in the impact concept is the simple assumption that larger amounts of pollutant results in larger impact as compared to smaller amounts of pollutants. Therefore, two areas equal in size which receives a large and a small amount of pollutant will be impacted to a large and a small extent respectively.

The *duration* of a pollutant within a water body is likewise a natural part of the 'impact' concept. The basic assumption is that the longer the duration the larger the impact will be. Thus, two areas of equal size which are exposed to a long and a short period of pollution with similar magnitude will be impacted to a large and small degree respectively.

For oil on open waters the result of the impact calculation will be given in the unit 'amount times time per area unit' (e.g. tonnes*hours/km^2).

2 Onshore

For oil onshore the result will be given as amount of oil which hits the shoreline in the course of a spill event.

8.2.3 Modelling of spreading and decay

The goal is to calculate the occurrence of oil under a large number of combinations of conditions. The basic problem is that detailed modelling of each and every spill event is too costly in terms of computer power. On the other hand, a strategic analysis of the risk of oil spills requires a large number of combinations of conditions to be simulated. To overcome this problem the following method is applied: Detailed models are applied for simulation of a few selected scenarios. From these results a simple model is established, which can calculate a large number of scenarios in a short time.

The drift, spreading and decay of oil is first calculated for selected key scenarios with complex and detailed models (MIKE3, SeaTrackWeb, Ice models, analytical models) for a number of oil types, wind- and temperature conditions, spill locations and -quantities etc.

The result is seen in schematic form in figure 2. The spill is modelled as circular. The spill is drifting with time in a direction and at a speed determined by the relation between wind, current and ice coverage in the area considered. The diameter of the spill is increased with time and the thickness is reduced correspondingly.

The decay, including emulsification, is modelled as a change in the mass of the spill as a function of time. The example in the figure includes a heavy oil type for which emulsification takes place resulting in a larger mass. The figure further shows the modelling of submerged fuel oil (IFO 380) where the oil slick is assumed to propagate at a reduced speed beneath the water surface. Under such condition decay does not take place and remediation is further not possible.

Ice cover is modelled as a condition which modifies the above description of drift and decay. The ice cover is modelled as complete ice cover, broken ice or no ice. In case of complete ice cover it is assumed that the oil spill remains at the same position with its characteristic diameter and thickness, and that no decay occurs.

In case of broken ice it is assumed that the entire oil spill adhere to the ice and that drifting hereof follows the drift velocity and direction of ice. The drifting of oil in broken ice is usually faster than drifting of oil in open waters, because of the larger wind effects on ice. For oil in broken ice it is assumed that the diameter of the spill remains the same. Oil in broken ice will tend to concentrate in leads, which is exposed to the atmosphere, wherefore decay is included. Thus the thickness of the oil spill can change.

In case of no ice, the transport and decay pattern follows that of oil in open waters. A practical definition of the transition between complete ice cover and broken ice, and between broken ice and ice free waters needs to be developed. Advanced ice models or data interpretation will be applied for the selected key scenarios, which form the basis for the simpler model description given above.

Finally the figure shows the effect of changed drift direction once the oil slick enters a new hydrographical area with different characteristics.

Submergence of oil is assumed possible for spill of fuel oil (freight classification 20 and heavy bunker fuel oil), but not for inadvertent spills or oil spills made on purpose. The probability of submergence is set to 0.25 for freight classification 20 and to 0.5 for heavy fuel bunker oil. In both cases it is assumed that 30 % of the spill submerges.

8.2.4 Modelling of the emergency response

It is assumed that the emergency response is able to effectively fight spill of oil and floating chemicals on the water surface as well as in ice.

The emergence response applies a wide range of different equipment including ships, barges, pumps, skimmers, booms and barriers as well as different hardware such as radar etc. For oil spills in broken ice or in complete ice covered waters it is assumed that special equipment is used. To describe the effect of the emergency response on the oil spill in a practical manner in the model complex, the response methods are reduced to include only the capacity of pumps and skimmers, as well as the equipment applied to convey the spill to the skimmers, e.g. booms attached to tow boats. The effect of the emergency response is modelled as a reduction of the amount of oil in the circular oil slick. The diameter hereof is unchanged, while the thickness reduces.

To calculate the effect of the emergency response it is chosen to define an artificial model response which replicates a possible and realistic emergency response, without simulating the actual emergency response. It is assumed that the response is carried out in three isolated actions at times T1, T2 and T3, so that the total response capacity increases with time.

The capacity for oil removal is calculated on basis of the total number of oil skimmers and pumps, as well as the total length of booms that is available.

In addition the modelling contains a number of conditions which may influence the effectiveness of the emergency response, such as visibility, darkness, limiting significant wave height etc. A reduced effectiveness is assumed for compounds labelled with Fire Hazard Class 'red' and Health Hazard Class 'red'. The modelling of the artificial response is shown in figure 3. The response is shown for Danish conditions but will have to be expanded to include the conditions of the other countries around the Baltic Sea.

The modelling provides an opportunity for evaluating the effect on the environment from changes in the emergency response. Different response strategies can be defined for the various waters of the Baltic Sea.

Table 8.1 Overview of input parameters for description of artificial emergency response

Parameter	Dimension	Model-response
Accumulated capacity of pump-skimmer system at time T1, T2 and T3	m³/h	Cap1: 0*) Cap2: 50 Cap3: 100
Accumulated. length of booms at time T1, T2 and T3	m	L1: 300*) L2: 600 L3: 1200
Alarm-combat time T1, T2 and T3	Hour	T1 : 2 T2 : 4 T3 : 6
Ice cover coefficient (relative increase in alarm combat time dependent on ice coverage)	non-dimensional	Ice covered: 1,50 Broken ice : 1,25 No ice : 1,00
Tow speed at time T1, T2 and T3	Knot	V1: 1 V2: 1 V3: 1
Visibility coefficient (ratio of the time where combat not is possible due to fog and haze)	non-dimensional	Spring: 0,02 Summer.: 0,01 Fall.: 0,02 Winter: 0,04
Darkness coefficient (ratio of time where combat not is possible due to too little daylight)	non-dimensional	Spring: 0,4 Summer: 0,2 Fall: 0,4 Winter: 0,6
Max. significant wave height	m	1,3
Recovery efficiency for chemicals compared to oil	non-dimensional	0,5
Reduction factor for fire hazard class "red"	non-dimensional	0,7
Reduction factor for health hazard class "red"	Non-dimensional	0,7

*) At time T1 it is assumed that only booms arrive to the oil spill. Therefore the pump capacity is set to 0 at time T1. However, in the modelling it is assumed that a certain amount of oil arrives at the boom during T1. The arrival rate is assumed to be 7 m^3/hour, which with a T1 of 2 hours gives 14 m^3. This is the amount which the booms are assumed to be able to hold back.

8.2.5 Model and data basis

The basis for the detailed modelling is a number of recognized models (MIKE3, SeaTrackWeb, Ice models and analytical calculation methods) which in detail describe the transport processes of an oil spill. The spreading of oil on the water surface is calculated from traditional formulas. In the calculations information on oil type, viscosity, temperature, density, etc. is applied. The drift of the oil with wind and current is calculated on basis of the detailed hydraulic modelling. The decay of the oil includes evaporation, emulsification and removal and is described as a function of viscosity (dependent on oil type and temperature), amount, wind and the effect of the emergency response by removing oil from the water surface.

Besides from the process description, it is important that the models are forced with correct and relevant meteorological and oceanographic data. To obtain a good description of the development of an oil spill, it is important that realistic combinations of wind and currents are applied.

To select wind and current data for the detailed modelling of selected oil spills, design periods with statistical properties, which match the selected scenarios, must be selected.

Data should be selected so that all four seasons are represented and that varying ice coverage is included.

8.3 Soluble chemicals

8.3.1 Introduction

The modelling of the spreading of soluble chemicals is included in the risk assessment as a means of modelling the impact and risk of impact and damage on the marine environment.

The combat of soluble chemicals is very difficult and is not carried out presently. Combat is only possible in special cases, primarily in confined water bodies such as harbours, which is not considered here. Therefore, the combat is not modelled.

The modelling of the impact from soluble chemicals is described in the following.

8.3.2 Principles for measurement of impact

The models for description of oil spills cannot be applied for calculation of the dilution of soluble compounds. The impact from spills of soluble chemicals is calculated on basis of the generalised descriptions of dilution through transport and dispersion of miscible fluids in the ocean. Decay of the soluble chemicals is not included.

The dilution calculations are carried out by calculating the distance between the emission point and the location where the concentration is less than the official threshold values for eco-toxicological impact on marine organisms. Such threshold values are determined by experiments using various types of chemicals.

All calculation cells in the model, which have concentrations above the threshold values, are impacted. There is no consideration of various degrees of impact.

8.3.3 Modelling of impact

The model for dilution of substance is based on the traditional dilution calculation, which assumes a Gaussian distribution, and which assumes stationary conditions. The input parameters to the model include the threshold value for the substance, the amount and concentration of substance released, the vertical location of the injection point, the current velocity, water depth and dispersion coefficient. This type of dilution calculation is standard practice for assessments for the Danish offshore sector in the North Sea.

8.3.4 Model and data basis

The applied model is called the PEC/PNEC model, which is an abbreviation of Predicted Effect Concentration / Predicted No Effect Concentration. The model calculates the distance where the calculated concentration is equal to the threshold value, below which there is no detectable effect on marine organisms.

This means that the geographical extent of impact from a highly toxic substance is larger than the extent for a less toxic substance, provided that the two substances are diluted equally.

On basis of the calculated distance from the spill location, a width of the polluted plume is determined assuming that this is 20 % of the plume length. This geometrical relation is applied, firstly because it is practical, and secondly because it is based on experience from the marine environment.

8.4 Sinking chemicals

It is assumed that chemicals which sink are not transported significantly with wind and current action while sinking. It is likewise assumed that the chemicals cannot be mobilized once settled to the seabed.

The impact is therefore described as amount of mass (tonnes) per calculation cell, which is dependent on the magnitude of the spill, since only calculation cells in which spill takes place are impacted.

Combat is not included in the modelling since it is assumed that the substance will rest on the seabed, and hardly ever will be removed by e.g. a grab sampler.

The various compounds classified with 'red' and 'yellow' labels respectively can be considered to have the same impact on the environment, as these substances constitute a very minor part of the total transport of chemicals.

8.5 Discussion

In a previous study of risk analysis in the Danish waters the uncertainty in the modelling of the impacts has been assessed. It appears that the process descriptions do not contain significant uncertainties.

The uncertainty on the environmental risk is being reduced due to the many integrations through the various scenarios, which form the basis for the risk assessment. The purpose of the analysis is to evaluate the integrated environmental impact considering various scenarios of ship traffic and different types of emergency response. The relative difference between the results will give a qualitative indication of whether the environmental risk will be reduced or increased. Hence it will be possible to assess the relative effect on the environmental risk for different scenarios.

9 Abbreviations

AIS	Automatic Identification System
BRISK	Project on sub-regional risk of spill of oil and hazardous substances in the Baltic Sea
ECDIS	Electronic Chart Display and Information System
EEZ	Exclusive economic zone
HELCOM	Baltic Marine Environment Protection Commission (also: Helsinki Commission)
IMO	International Maritime Organisation
RRM	Risk-reducing measure
SOLAS	International Convention for Safety of Life at Sea
STS	Ship-to-ship transfer
VTS	Vessel traffic service

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