Juned Akhtar
Viggo Jean-Hansen
TØI report 1037/2009

Institute of Transport Economics
Norwegian Centre for Transport Research

Effects of proposed ship routeing off the Norwegian coast

Part 2 Utsira - Oslo fjord

TØI report
1037/2009

Effects of proposed ship routeing off the Norwegian coast

Part 2 Utsira - Oslo fjord

Juned Akhtar
Viggo Jean-Hansen

ISSN 0808-1190
ISBN 978-82-1007-4 Paper version
ISBN 978-82-1006-7 Electronic version
Oslo, December 2009

Title: Effects of proposed ship routeing off the Norwegian coast. Part 2 Utsira - Oslo fjord

Tittel: Konsekvenser av forslag til ny farled utenfor norskekysten. Del 2 Utsira - Oslofjorden

Author(s):	Juned Akhtar Viggo Jean-Hansen	**Forfattere:**	Juned Akhtar Viggo Jean-Hansen
Date:	12.2009	**Dato:**	12.2009
TØI report:	1037/2009	**TØI rapport:**	1037/2009
Pages	131	**Sider**	131
ISBN Paper:	978-82-480-1007-4	**ISBN Papir:**	978-82-480-1007-4
ISBN Electronic:	978-82-480-1006-7	**ISBN Elektronisk:**	978-82-480-1006-7
ISSN	0808-1190	**ISSN**	0808-1190
Financed by:	The Norwegian Coastal Administration	**Finansieringskilde:**	Kystverket
Project:	3512 - Analyse av effekten av foreslåtte IMO rutetiltak utenfor norskekysten	**Prosjekt:**	3512 - Analyse av effekten av foreslåtte IMO rutetiltak utenfor norskekysten
Project manager:	Juned Akhtar	**Prosjektleder:**	Juned Akhtar
Quality manager:	Torkel Bjørnskau	**Kvalitetsansvarlig:**	Torkel Bjørnskau
Key words:	Accidents Marine vessel Oil spills Risk Routeing	**Emneord:**	Farled Oljeutslipp Risiko Skip Ulykker

Summary:

The effects of transferring large vessels (> 5000 Gross Tonnes) and vessels carrying hazardous goods to a proposed shipping route along the Norwegian coastline from Utsira to the Oslo fjord have been studied. The aim of the routeing measure is to separate the traffic and route the ships farther away from the coast to reduce oil spills. The effects of the routing measure have been analyzed by use of accident simulations and case scenarios. The results reveal that one may expect substantial reductions in oil spill volumes when traffic is transferred to the proposed route. The effects are even greater when ship traffic forecasts for 2025 are used. The reduction in total oil spill volumes is predominantly a result of an expected decline in tanker oil spills.

Sammendrag:

Effektene av å etablere en ny farled for skip over 5000 brutto tonn samt skip som fører farlig last langs norskekysten mellom Utsira og Oslofjorden er analysert. Målet med tiltaket er å separere skipstrafikken og lede trafikken lengre ut fra kysten for å redusere faren for oljeutslipp og oljesøl. Effektene av tiltaket er analysert ved hjelp simuleringer av ulykker og ulykkeskonsekvenser og gjennom analyser av to case-scenarioer. Resultatene viser at man kan forvente en kraftig reduksjon i omfanget av oljeutslipp og oljesøl ved å innføre den nye farleden. Effektene er enda større når trafikkprognoser for 2025 benyttes i simuleringene. Reduksjonene i omfang av oljeutslipp er særlig sterke for tankskip.

Language of report: English

Institute of Transport Economics
Gaustadalleen 21, 0349 Oslo, Norway
Telefon 22 57 38 00 - www.toi.no

Transportøkonomisk Institutt
Gaustadalleen 21, 0349 Oslo
Telefon 22 57 38 00 - www.toi.no

Preface

Ship routeing schemes have been established in most of the major, congested shipping areas of the world. The number of accidents has often been dramatically lowered. The Norwegian Coastal Administration has proposed a routeing measure for transferring ship traffic above 5000 GT and vessels carrying dangerous or polluting goods in international voyage off the Norwegian coast all the way from Røst to the Oslo fjord. The present report investigates the effects of this proposed routeing measure from Utsira to the Oslo fjord. The effects of the proposed routeing measure for the fairway from Røst to Utsira are presented in a separate report.

The study was funded by The Norwegian Coastal administration (NCA). Project manager at the NCA was Trond Langemyr.

The principal author of this report is Research Engineer Juned Akhtar, who has been project manager at the Institute of Transport Economics (TØI). Senior Researcher Viggo Jean-Hansen (TØI) has been responsible for the ship traffic forecasts presented. M. Sc. Jørn Harald S. Andersen at Norconsult and Cand. Scient. Elisabeth Lundsør performed the oil spill analyses linked to the two case scenarios studied. Managing Director John Evensen at Maritime Preparedness Operations AS has given valuable comments on the methodology used. Principal Consultant Tim Fowler at Det Norske Veritas, London performed the accident and oil spill simulations in the report.

Comments to earlier drafts of this report have been given by Chief Researcher Torkel Bjørnskau (TØI) and Øystein Linnestad and Trond Langemyr from NCA. Torkel Bjørnskau has been responsible for formal quality assurance. Secretary Trude Rømming has been responsible for the final editing of the manuscript.

Oslo, December 2009
Institute of Transport Economics

Lasse Fridstrøm	*Torkel Bjørnskau*
Managing Director	Chief Researcher

Contents

Appendices

Summary:

Effects of proposed ship routeing off the Norwegian coast
Part 2 Utsira - Oslo fjord

The Norwegian Coastal Administration (NCA) commissioned The Institute of Transport Economics (TØI) to conduct a risk assessment of a proposed ship routeing measure off the Norwegian coast from Utsira to the Oslo fjord.

The proposed measure is to route tankers and other heavy ship traffic (over 5.000 gross tonnes (GT)) with high environmental risk potential farther away from the coastline from Utsira to the Oslo fjord. The proposed measure includes a traffic separation scheme separating traffic going in the different directions.

The idea behind the proposal is that when ships travel on the proposed route any emergencies or possible oil spills will occur farther away from the coast, giving the authorities more time to react and enable emergency towing or oil spill response that may significantly reduce the overall environmental impact. Another effect is that possible oil spills from ship accidents will to a greater extent evaporate before reaching the coast.

The study has compared accident probabilities and consequences for the present routes and for the proposed route using traffic data for 2008 and traffic forecasts for the year 2025. The effects of transferring ship traffic to the proposed route have also been illustrated by use of two case scenarios.

Reduced accident and oil spill probabilities

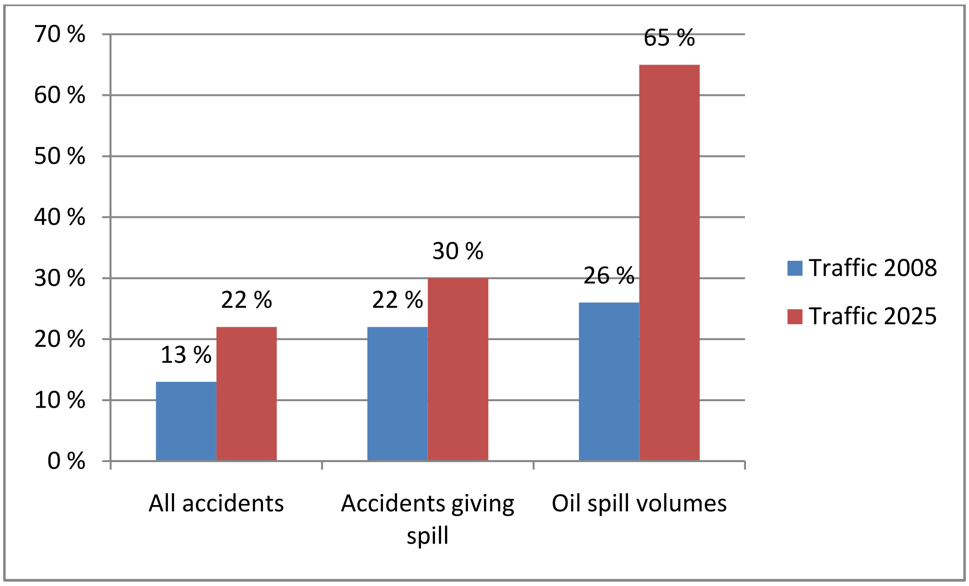
Today's traffic and a route model were charted by using data from the Automatic Identification System (AIS). A marine traffic simulation programme called MARCS, developed by DNV Technica, was used to simulate accidents and oil spill volumes both for today's route and for the proposed route, in both 2008 and 2025. Table S.1 and figure S.1 summarizes the results for all vessels.

Table S.1. Effects of proposed routeing on the expected number of all accidents, on oil spill accidents, and on the expected volume of oil spills, with traffic data for 2008 and 2025.

All vessels	All accidents [freq. per year]	Spill Accidents [freq. per year]	Oil spill + bunkers oil [tonnes per year]
Today's routes 2008	5.10	0.87	2110
Proposed route 2008	4.42	0.68	1560
Difference	0.68	0.19	550
Significance	Not sig.	Not sig.	Significant
Today's routes 2025	6.45	1.35	3940
Proposed route 2025	5.06	0.94	1380
Difference	1.43	0.41	2560
Significance	Not sig.	Not sig.	Significant

Source: TØI-report 1037/2009

The report can be ordered from:
Institute of Transport Economics, Gaustadalléen 21, NO 0349 Oslo
Telephone: +47 22 57 38 00 Telefax: +47 22 60 92 00



Source: TØI-report 1037/2009

Figure S.1. Expected effects of proposed routeing. Per cent change in all accidents, oil spill accidents and the volume of oil spills with traffic data for 2008 and 2025.

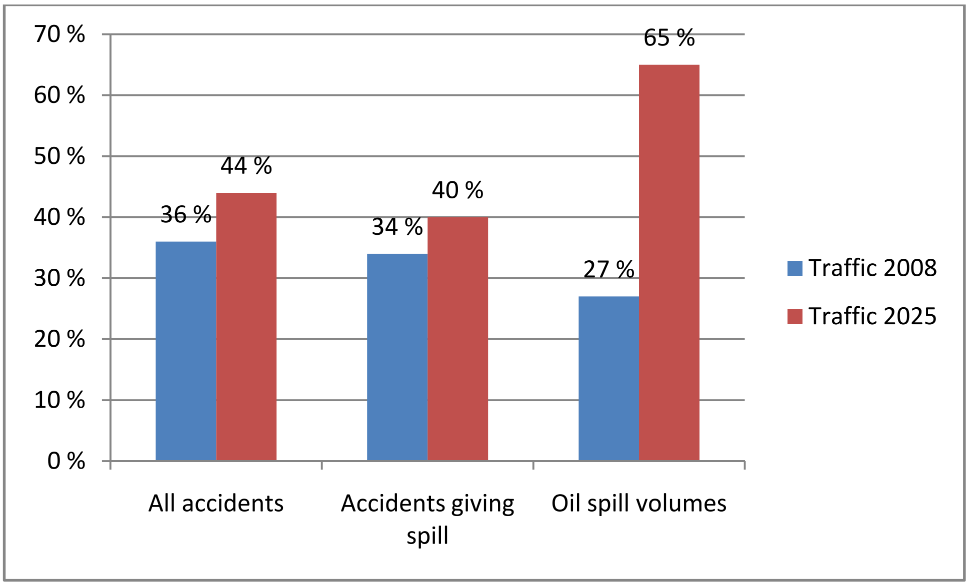
The proposed routeing of the ship traffic between Utsira and the Oslo fjord reduces the expected number of accidents and the expected oil spill volumes, both with ship traffic volumes as in 2008 and 2025. The expected reduction in oil spill volumes is particularly great when traffic forecasts for 2025 are used in the simulations.

Tankers are the major contributor to potentially large oil spill volumes, and when tankers are analyzed separately the effects are even stronger. This is revealed in table S.2 and figure S.2.

Table S.2. Effects of proposed routeing on the expected number of all tanker accidents, on oil spill accidents for tankers, and on the expected volume of oil spills for tankers, with traffic data for 2008 and 2025.

Tankers only	All accidents [freq. per year]	Spill Accidents [freq. per year]	Oil spill + bunkers oil [tonnes per year]
Today's routes 2008	1.08	0.47	2010
Proposed route 2008	0.69	0.31	1480
Difference	0.39	0.16	536
Significance	Not sig.	Not sig.	Significant
Today's routes 2025	2.45	0.94	3840
Proposed route 2025	1.37	0.57	1340
Difference	1.08	0.37	2500
Significance	Not sig.	Not sig.	Significant

Source: TØI-report 1037/2009



Source: TØI-report 1037/2009

Figure S.2. Expected effects of proposed routeing. Per cent change in tanker accidents, oil spill accidents for tankers, and the expected volume of oil spills for tankers, with traffic data for 2008 and 2025.

Transferring tanker traffic to the proposed new route gives over 30 per cent reductions in accidents and nearly 30 per cent reduction in oil spill volumes when traffic figures for 2008 are used in the simulations. When traffic forecasts for 2025 are used, accidents are reduced by at least 40 per cent and oil spill volumes are reduced by 65 per cent.

Environmental effects illustrated by oil spill scenarios

To oil spill scenarios, at Egersund and Ryvingen, have been constructed in order to analyze the effects of having oil spill accidents on the proposed route instead of on one of the routes used today. The scenarios clearly reveal that the probability of spill accidents decreases with the proposed measure. Also the probability of oil tanker collisions is smaller on the proposed new route than on today's routes, and given an oil spill accident the portion of the fuel or bunker oil reaching the shore is substantially reduced.

There are few adverse environmental effects of adopting the proposed routeing measure. The most important factor is a potentially larger coastline impact area for oil spills. For crude oil, this negative effect is counterbalanced by increased evaporation and natural degradation of oil resulting from increased distance to the cost. Fuel oil spills from locations along the proposed traffic lane may hit a larger impact area. It is, however, possible that this risk will be mitigated by increased time for oil spill response by the authorities, given an accident.

Conclusion

In sum it seems clear that the proposed routeing measures reduces both the probability of accidents and the consequences of possible accidents. Thus, adopting the proposed routeing measures will give a significant risk reduction.

The expected reduction in total oil spill volumes is predominantly a result of an expected decline in tanker oil spills. The proposed measure is in particular addressed towards managing these environmental risks mitigating the effects of the expected tanker traffic increase along the Norwegian coast. It seems, accordingly, reasonable to conclude that the proposed new route is a quite appropriate counter measure.

TØI-rapport 1037/2009
Forfattere: Juned Akhtar, Viggo Jean-Hansen
Oslo 2009, 131 sider

Sammendrag:

Konsekvenser av forslag til ny farled utenfor norskekysten

Del 2 Utsira - Oslofjorden

På oppdrag for Kystverket har Transportøkonomisk Institutt (TØI) utført kvantitative risikoanalyser som viser effekten av å innføre en alternativ farled for skip over 5000 brutto tonn, samt skip som fører farlig og/eller forurensende last utenfor norskekysten fra Utsira til Oslofjorden. Den nye farleden som inkluderer systemer for separasjon av trafikk, vil føre skipstrafikken i større avstand fra kysten.

I analysene er sannsynligheter for og konsekvenser av ulykker sammenlignet ved bruk av dagens farled og den alternative farleden med traffikdata fra 2008 og med prognostiserte trafikkdata for 2025. To scenarioer for oljeutslipp i utsatte områder har også blitt simulert og drøftet.

Færre ulykker og mindre utslipp med ny farled

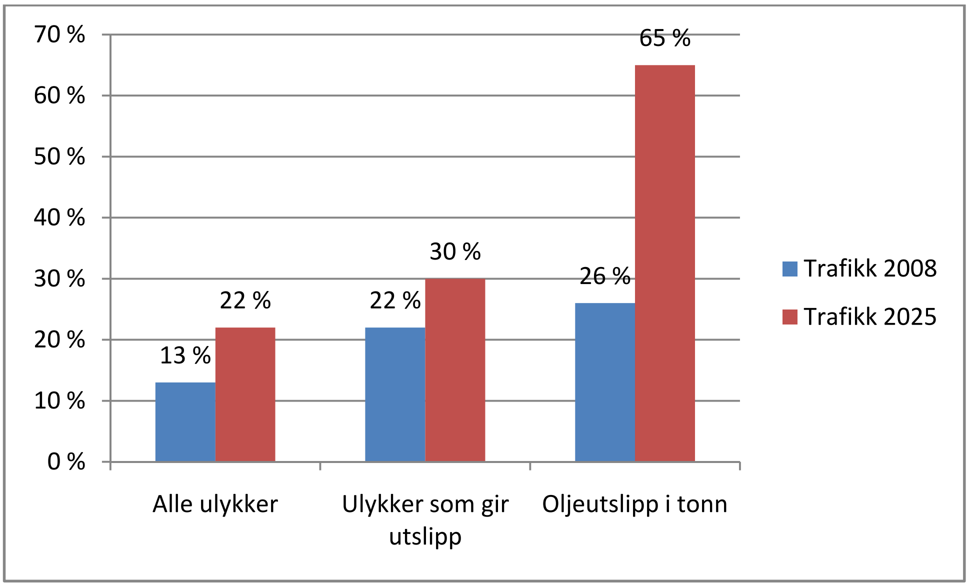
Trafikkdata for 2008 ble samlet fra Automatic Identification System (AIS) database. Trafikkdata for 2025 er basert på prognoser for skipstrafikk beregnet av Transportøkonomisk institutt. Et dataprogram for ulykker og utslipp utviklet av Det Norske Veritas, MARCS, ble brukt for å simulere hhv. totalt antall forventede ulykker, forventet antall ulykker som gir utslipp, forventet mengde oljeutslipp og forventet mengde utslipp av bunkersolje. Tabell S.1 og figur S.1 gir et sammendrag av resultatene fra simuleringene.

Tabell S.1. Forventet antall ulykker, antall ulykker som gir oljeutslipp og omfang av utslipp for alle fartøyer med dagens led og med foreslått ny led med trafikk for 2008 og prognostisert trafikk for 2025.

Alle fartøyer	Alle ulykker [antall per år]	Ulykker som gir utslipp [antall per år]	Oljeutslipp (inkl. bunkersolje) [tonn per år]
Dagens led 2008	5,10	0,87	2110
Foreslått led 2008	4,42	0,68	1560
Differanse	0,68	0,19	550
Signifikans	Ikke sig.	Ikke sig.	Signifikant
Dagens led 2025	6,45	1,35	3940
Foreslått led 2025	5,06	0,94	1380
Differanse	1,43	0,41	2560
Signifikans	Ikke sig.	Ikke sig.	Signifikant

Kilde: TØI-rapport 1037/2009

Rapporten kan bestilles fra:
Transportøkonomisk institutt, Gaustadalléen 21, NO 0349 Oslo
Telefon: 22 57 38 00   Telefax: 22 60 92 00



Kilde: TØI-rapport 1037/2009

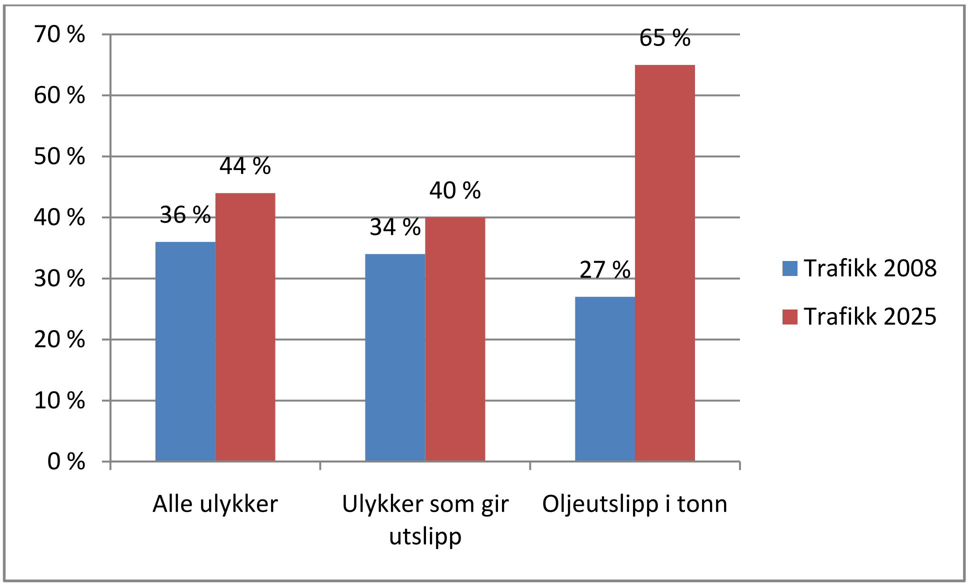
Figur S.1. Prosentvis endring i antall ulykker, antall ulykker som gir oljeutslipp og omfang av utslipp med dagens led og med foreslått ny led, med trafikk for 2008 og prognostisert trafikk for 2025.

Den foreslåtte alternative farleden gir signifikant mindre oljeutslipp sammenlignet med dagens led. Ser man på tankskip isolert, som gir det største bidraget til risikoen for oljeutslipp, er forbedringen enda større. Beregningene er basert på at den nye trafikkleden vil være obligatorisk for tankskip, noe som bidrar til den høye effekten, se tabell S.2 og figur S.2.

Tabell S.2. Forventet antall ulykker, antall ulykker som gir oljeutslipp og omfang av utslipp for tankskip med dagens led og med foreslått ny led, med trafikk for 2008 og prognostisert trafikk for 2025.

Tankskip	Alle ulykker [antall per år]	Ulykker som gir utslipp [antall per år]	Oljeutslipp (inkl. bunkersolje) [tonn per år]
Dagens led 2008	1,08	0,47	2010
Foreslått led 2008	0,69	0,31	1480
Differanse	0,39	0,16	536
Signifikans	Ikke sig.	Ikke sig.	Signifikant
Dagens led 2025	2,45	0,94	3840
Foreslått led 2025	1,37	0,57	1340
Differanse	1,08	0,37	2500
Signifikans	Ikke sig.	Ikke sig.	Signifikant

Kilde: TØI-rapport 1037/2009



Kilde: TØI-rapport 1037/2009

Figur S.2. Effekten av ny farled for tankskip. Forventet prosentvis reduksjon i antall ulykker totalt, ulykker som gir utslipp og omfang av utslipp av olje og bunkersolje, beregnet for trafikk i 2008 og prognostisert trafikk i 2025.

Ved å overføre tankskiptrafikken til den foreslåtte farleden forvente kan man forvente en reduksjon i antall ulykker med tankskip på 36 prosent og en nedgang i omfanget av oljeutslipp på 27 prosent, når trafikktall for 2008 er benyttet i simuleringene. Når prognostiserte tall for 2025 er brukt, blir antall ulykker redusert med over 40 prosent og omfanget av oljeutslipp reduseres med hele 65 prosent.

Miljøkonsekvenser illustrert med to utslippsscenarioer

To scenarioer ble valgt for å simulere effekter av oljeutslipp ved hhv. Egersund og Ryvingen for å illustrere konsekvenser av å føre trafikk over i den nye farleden. I begge scenarioene ble sannsynlighet for ulykker som gir utslipp og sannsynlighet for kollisjon for tankskip redusert i den nye farleden. Mengde olje som nådde kysten gikk også ned, og det tok lenger tid før oljen nådde land. I scenarioet ved Ryvingen vil oljeutslippet drive forbi kysten gitt at utslippet skjer i den foreslåtte farleden i følge simuleringene. Også ved Egersund er de negative miljøkonsekvensene av oljesøl betraktelig mindre med den foreslåtte farleden enn med dagens farled.

Det er få negative konsekvenser av å overføre trafikk til den foreslåtte farleden. En mulig uheldig virkninger kan være at oljesøl som når land kan gi skade på et større område når utslippet skjer lenger fra land, men dette vil motvirkes både av at mer av oljen blir oppløst i sjø og luft samt at myndighetene også får lenger tid til å håndtere utslippet.

Konklusjon

Å føre de relevante skipene over i den nye farleden langs norskekysten fra Utsira til Oslofjorden reduserer både sannsynligheten for skipsulykker og sannsynligheten for oljeutslipp betraktelig. De to scenarioene i rapporten indikerer at den nye farleden også reduserer forventet mengde olje som treffer land gitt en ulykke med oljeutslipp. Resultatene viser at effekten på tankskipulykker og utslipp fra tankskip er svært gunstig. Dette har også vært en hovedintensjon bak det foreslåtte tiltaket. Det er følgelig grunn til å konkludere med at lede tankskiptrafikken over i den foreslåtte farleden er et svært godt tiltak for å møte miljøutfordringene som tankskiptrafikken langs norskekysten representerer.

Definition of terms

AIS: Automatic Identification System. A ship-borne transponder broadcasting information about the ship, the voyage, and several other safety related issues.

Collision: An event type that occurs when a ship is struck by another ship.

Drift grounding: An event type that occurs when a ship loses its ability to navigate, through loss of steering or propulsion, and is blown onto the shoreline before it is either taken in tow or is repaired.

DWT: Dead weight tonnage

Event frequency: The number of events, such as inter-ship collisions, that occur per year at a specified location or within a defined area.

GT: Gross tonnage

Historical frequency: A frequency derived from historical data.

IMO: International Maritime Organization

MARCS: Marine Accident Risk Calculation System. An accident and risk simulation programme developed by DNV Technica.

NCA: The Norwegian Coastal Administration

NM: Nautical Mile = 1.852 kilometers

Powered grounding: An event type that occurs when a tanker collides with the shoreline whilst underway.

Risk: The frequency of a hazard multiplied by its consequence. The term is however often used as the mere probability of an accident/incident with adverse consequences.

SOLAS: International Convention for the Safety of Life at Sea

Structural failure: An event type that occurs when a ship sinks in heavy weather or loses its structural integrity due to mechanical failure.

VTS: Vessel traffic services

1 Introduction

1.1 Background

Commercial shipping has important impacts on the wider environment, due to the ordinary release of exhaust gases etc., but in particular due to the risk of accidents with the unintended release of toxic chemicals and oil spills. Unfortunately shipping accidents may have very severe negative impacts, particularly to coastal regions, due to the potential release of very large quantities of hazardous or eco-toxic cargo materials such as crude oil.

Thus, prudent authorities who have the responsibility for pollution response in coastal regions seek to estimate the risks to which they may need to respond, and to prepare appropriate contingency plans and response options in order to manage the risks imposed.

In order to deal with ship accidents promptly and effectively, spill response is considered to be a very important mitigation measure. Norwegian authorities having for a long time been concerned about the risk of oil spills, they have implemented a series of measures in order to reduce the likelihood of accidents, for instance a new Vessel Traffic Service (VTS) service for North Norway located in Vardø, and reinforced tugboat preparedness.

One of the key measures adopted to reduce the risk of ship accidents and oil spills is to impose sailing routes farther away from the coast. Along the northern Norwegian coastline between Vardø and Røst such a more remote sailing route has been imposed. According to the Norwegian Coastal Administration (NCA), the experiences so far have been positive.

1.1.1 Increased oil transport

Since 2002 the oil transport in the Barents Sea from Russia has increased significantly. In 2002, 4 million tonnes of oil were shipped westward through the Barents Sea. In 2008 the number had increased to 10.8 million tonnes. Forecasts for 2025 estimate an 60 per cent increase in the oil transport and a tenfold increase in the gas tanker transport (Hovi & Madslien 2008; Bambulyak & Frantzen, 2009).

All oil transport imposes a risk of acute oil pollution. Consequently an increase in the maritime and off shore petroleum activity will increase the risk. Experience shows that only 10-15% of oil spills in the Arctic Sea can be removed by the current level of preparedness (Bambulyak & Frantzen, 2009). The rest will have to be left to the natural evaporation or breakdown over time. The major contributor to this risk is tankers transporting oil from Russia along the Norwegian coast (Kystverket, 2006a).

1.1.2 Risk of an environmental crisis

Since 2000 Norway has experienced several adverse events that could have resulted in major environmental crises. One example was when the ship “John R” stranded and broke into two pieces. Most of the oil carried by the ship was removed before the ship broke, thus inflicting only minor environmental damages. Another example was the near-accident of a 100 000 tonnes Russian oil tanker with engine failure that drifted towards the coast.

There have also been ship accidents leading to oil spills and pollution. One example is the “MS Server” grounding north-west of Bergen in January 2007. The bad weather the following days made the recovery of heavy fuel oil difficult. Around 400 tonnes of heavy fuel oil was released into the environment.

The most recent event took place in July 2009 when the Panama registered vessel “Full City” grounded south of Langesund in Southern Norway. The ship suffered severe damage to her hull, and bunker oil escaped to the sea and polluted the shorelines. Some of the affected areas were special protected areas and bird sanctuaries.

It is worth mentioning that Norway has experienced a steady rise in the number of groundings since 2004. In 2008 103 groundings were registered. Although the majority of these groundings involve medium size vessels, i.e. 500-5000 gross tonnage (GT), the trend is alarming (Sjøfartsdirektoratet, 2009).

1.1.3 The North Sea

The North Sea is rich in natural resources, thus being of great economic interest. Along with the fishery resources it also has huge recourses of gas and oil, resulting in high transport activity. Recently launched projects such as the gas production from the world’s largest offshore gas reserve, Shtockman, and the production of LNG from Snøhvit and oil from Goliat, will add to today’s already high maritime activity along the coast of Norway and thus increase the risk of environmental damages. The marine flora and fauna are vulnerable; the Norwegian coast line is home to approximately 19.5 million individual sea birds and 4.5 million breeding pairs (Loeng & Drinkwater, 2007).

1.1.4 The proposed measure

The proposed measure is to route tankers and other heavy ship traffic (over 5.000 GT) with high environmental risk potential farther away from the coastline from Røst to the Oslo fjord. The idea behind the proposal is that any emergencies or possible oil spills will then occur farther away from the coast, giving the authorities more time to react and enable emergency towing or oil spill response that may significantly reduce the overall environmental impact. Another effect is that possible oil spills from ship accidents will then to a greater extent evaporate before reaching the coast.

1.2 Research objective

The overall objective of this study is to produce quantitative risk analyses in order to estimate the effects of the proposed measure. The main research objective is thus to compare the accident risks and accident consequences with and without the proposed route measures implemented.

Risk calculations will be conducted both by use of current ship traffic volumes and by use of traffic forecasts for the year 2025.

1.3 Report structure

This report is structured as follows. In chapter 2 we describe the methodological approach chosen and in chapter 3 the data base used. Chapters 4 and 5 explain the routes used today and the proposed new route. In chapter 6 traffic forecasts are presented, while chapter 7 exhibits the results of the risk calculations. In chapter 8 we present the results of two case scenarios. A discussion of results and a conclusion follow in chapter 9.

In general the current main report summarises the model approach, presents the results and discusses their implications. Further information about the data used and the calculations made can be found in the appendices. Also the two case scenarios of accidents producing oil spills are presented in more detail in an appendix.

The appendices are as follows:

1. Traffic on today's routes and on the proposed route
2. Vessel velocity and length
3. Obstacles on or near the routes
4. Description of the Marine Accident Risk Calculation System (MARCS)
5. Data input in MARCS
6. MARCS results
7. Calculation of confidence intervals
8. Two case scenarios. Report from Norconsult
9. Accident figures for the scenario areas
10. Risk assessment of alternative tanker routing. Report from DNV

2 The approach

The approach adopted is to compare the proposed recommended route with today's routes given traffic data of 2008 and 2025. An accident and risk simulation programme called MARCS, developed by DNV Technica, was used for this purpose. The MARCS programme is described in detail in Appendix 4.

2.1 Traffic forecasts

The traffic data from 2008 was used to develop a forecast for 2025. The forecast allows for differentiated traffic developments according to ship types, coastline sections etc. along various parts of the coast. Chapter 6 describes in detail how the forecast has been made.

Traffic data both for 2008 and for 2025 have been entered into the MARCS model in order to calculate accident and oil spill probabilities.

2.2 Risk simulations

The primary focus of the risk simulations was to assess the risk of oil spills per year. Historical data for the North Sea from the Det Norske Veritas' (DNV) database on oil spill events from tankers was used to identify the major causes of oil spills. These input data, which were entered into the MARCS model, are described in more detail in Appendix 5.

The major causes of oil spill were according to the DNV database identified as:

- Inter-ship collisions
- Tanker grounding (powered and drifts events)
- Collisions between tankers and offshore platforms
- Fire and explosions whilst underway
- Structural failure/foundering
- Cargo transfer operations in open waters (lightering).

The simulation combines statistical data with information about the lanes, marine traffic data, environmental data, and operational data, in order to calculate the risk of accident and the risk of oil spills. The details of the data and the simulation are given in chapter 7.

The Norwegian coast is long with varying climatic conditions. The probabilities that have been estimated in this study are accumulated probabilities that are helpful to assess the total impact of the measure. Plots of the study area are also generated and illustrated in the report.

2.3 Case scenarios

Two case scenarios have been selected in order to simulate the consequences given specific accidents. These cases which were carefully selected in co-operation with the Norwegian Coastal Administration (NCA), Maritime Preparedness Operations AS (MAPO) and Norconsult. They are intended to serve as examples and are described in Appendix 8.

The scenarios were selected based on the following criteria:

- The national dimensioning of oil spill scenarios defined by the Ministry of Fisheries and Coastal Affairs (20 000 m^3 crude oil, 1000 m^3 or 5000 m^3 heavy fuel oil)
- AIS data and identification of high density traffic "hot spots"
- Potential threat to coastline and vulnerable marine resources
- Prevailing wind and sea current conditions, and inside operational window for oil spill response

As part of the national emergency response system an oil drift model service is provided by the Norwegian Meteorological Institute, Marine Forecasting Centre (DNMI). Based on sophisticated ocean and weather models, end users such as NCA and major private contingency organisations can access this tool through a web interface. By use of this tool NCA has provided the oil drift simulations to this report.

3 Marine traffic data

3.1 AIS data

The universal Automatic Identification System – AIS – is a ship-borne transponder that broadcasts information about the ship, the voyage, and several safety-related issues.

The coverage of the system is similar to other VHF applications, i.e. it depends on the range to the horizon from the antenna. A total of 37 stations form the AIS network in Norway. Typically the range is 45 NM from the coast. Research is currently in progress in order to increase this range by using a space-based AIS receiver which will have a range of up to 1000 NM (Eriksen, Høye, Narheim, & Meland, 2006). AIS carriage requirements are given in the SOLAS convention chapter V, regulation 19, paragraph 2.4.

Ships transmit updated AIS information with 2-30 seconds' intervals. The frequency varies by type of ship. Information from AIS can be used to construct advanced data bases on ship movements, forming the basis of the ship traffic data used in our analyses.

3.2 Data selection

The proposed route was designed for vessels carrying hazardous/polluting cargo and for all vessels above 5000 GT. Our AIS data files did, however, not contain information about vessel weight (GT and DWT). Yet, by using the IMO number, NCA was able to utilize Lloyd's register to collect the vessel weights.

We specified the following six relevant vessel types according to their potential for bunker and cargo spills:

- Chemical tanker
- Gas tanker
- Oil tanker
- Cargo ships larger than 5000 GT
- Other ships larger than 5000 GT
- All other vessels

3.3 Traffic volumes in 2008

By first defining the routes of today's traffic we could define specific crossing sections on the routes. Data from the AIS database were utilized in order to collect information on all vessels on the crossing sections in the year 2008. For our analyses we required AIS data of traffic volumes sorted by weight (GT and DWT), tanker type, IMO number and speed. These data were then used as input into the MARCS program.

4 Today's traffic pattern

The traffic data was used to plot all vessels of 100 metres length or more for the period 2008-2009. 100 metres was chosen after checking the AIS files and confirming that all tankers were at least 100 metres. The average length of the entire fleet was calculated to be 165 metres.

The plots in figure 4.1 and 4.2 yield the typically used routes for large vessels today. A single sailing is marked with a yellow line. Areas with high density are marked red. On the basis of these traffic data, today's routes could be determined. Caution was taken to define a new lane at every shift of traffic density or angle. At every corner of these lines, a new lane was defined and the AIS data extension was made. In total 8 main lanes and 6 crossing lanes were defined for routes from Utsira to Oslo fjord. In the plots, today's routes are indicated by the parallel lines running along the coast. The crossing lanes are indicated as shaded grey areas.

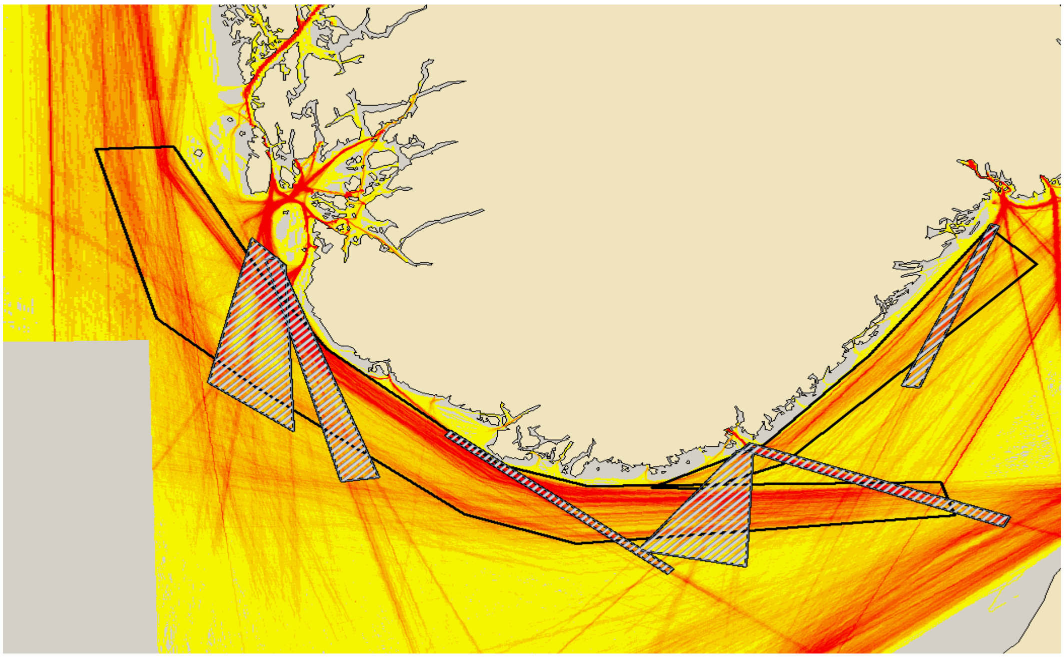


Figure 4.1 Today's routes Utsira-Oslo fjord. Source: NCA

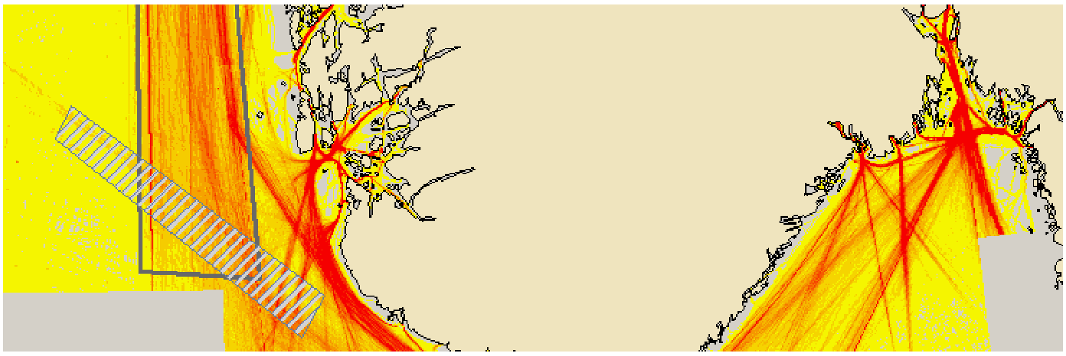


Figure 4.2 Today's routes near Utsira and near/in the Oslo fjord. Source: NCA

4.1 Two-way traffic

Today's routes have no separation schemes. However the oil transport flow in the Norwegian and North Sea goes from north to south and from the offshore oil platforms to the plants onshore. Hence two lanes were defined on top of each other for the tankers, one fully loaded (north-south) and one mainly empty going back towards north. For the traffic east-west it is assumed that tankers are half loaded either way. The rest of the traffic was defined as constantly half loaded.

4.2 Objects on or near the routes

Platforms, wind parks etc. are installations at sea that vessels have to navigate past. In the case of drifting or other emergency situations there can be collisions with these structures leading to oil spill, loss of ship etc. The Norwegian Coastal Administration provided a list of all the installations in our study area, 101 in total. These installations are mainly oil platforms located in the (south) western part of the area, and few of them will in fact be of relevance for the proposed routeing between Utsira and the Oslo fjord. Nevertheless, this information was also entered into the MARCS model. The complete list of the installations is given in Appendix 3.

5 The proposed route

The proposed route has been identified by an expert group consisting of relevant stakeholders. The following points were considered while constructing the proposed ship routing for tankers and vessels above 5000 GT:

1. IMO "design criteria" for the ships' routing measures

2. Environmental considerations
   a. Routing traffic as far from shore as practicable, but limited by the AIS range.
   b. Special concern has been given to areas along the route and off the coast that are vulnerable to oil spills

3. Industry and commerce – permanent and stationary activity.
   a. Consideration for stationary fishing areas
   b. Consideration of solid surface offshore installations (including future installations that will be in place when the proposed route measures will be effective in 2011)
   c. Considerations for shipping – avoiding disproportionate large changes to the distance travelled and safeguarding the current permanent cross-traffic.

4. Industry and commerce – activities that are not fixed or stationary
   a. Pelagic fishing
   b. Potential high-activity areas, i.e. areas with a high probability of becoming places of extensive commercial activity that may affect the shipping industry within the next 5 years.

5.1 Traffic on the proposed route

Today's routes and the proposed route differ with respect to vessel density, width and length. Our analysis is based on a scenario where vessels above 5000 GT and vessels carrying dangerous and/or polluting goods are transferred to the proposed route, leaving the rest of the ships on today's routes. In other words, all ship types except the last defined category ("all other vessels") in section 3.2. will be transferred to the proposed recommended route.

The plots in figure 5.1 show the proposed route. For co-ordinates please see Appendix 1.

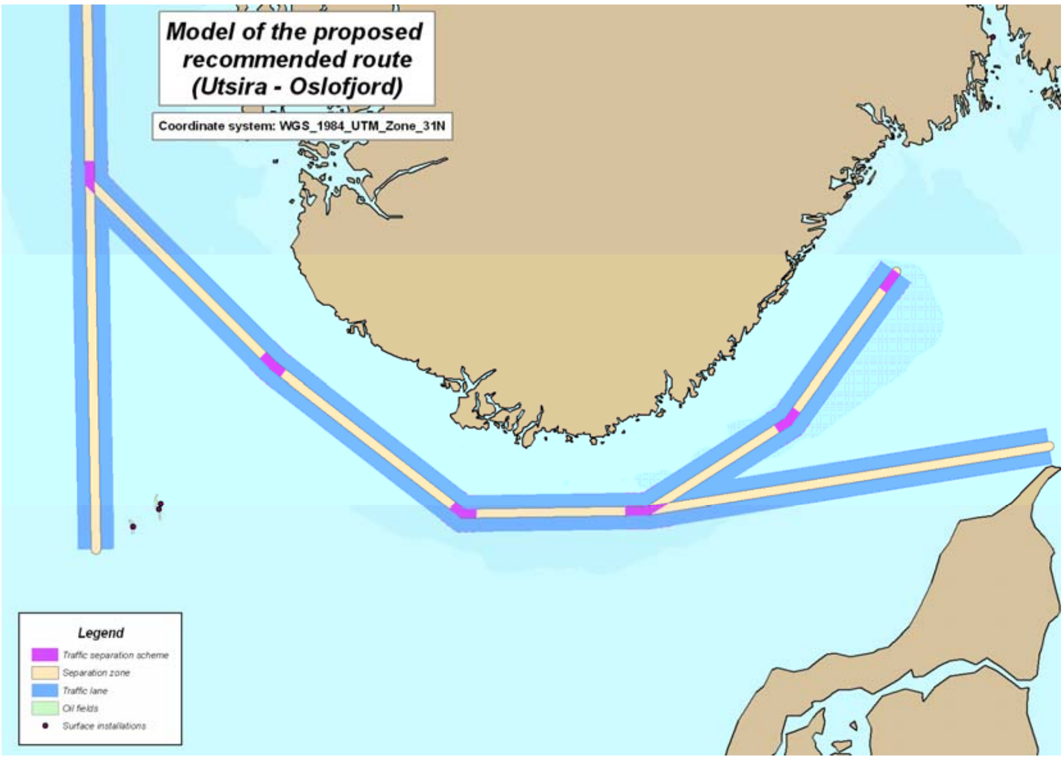


Figure 5.1 Proposed route Utsira-Oslo fjord. Source: NCA

6 Traffic forecast

TØI has established a forecast for the ship traffic from 2008 to 2025 for the whole fairway between Røst and the Oslo fjord. This chapter presents the basis of the forecast and some additional comments.

6.1 Types of vessels

We identified six types of relevant ships in section 3.2: Chemical tankers, gas tankers, oil tankers, cargo ships > 5000 GT, other ships > 5000 GT and all other vessels.

The ships sailing in the fairway will be of many different nationalities. Ships to and from the Norwegian ports dominate the traffic. Sea freight typically consists of long haul transport of goods having low value per tonne.

Passenger traffic will be limited and predominantly consist of cruise ships (> 5000 GT) coming from Europe and America visiting Norwegian fjords both on the west coast and the Oslo fjord, North Cape and the coast around Svalbard.

Small tankers carrying fuel to the fishing fleet, oil and gas for residential heating etc. and other types of cargo ships are also part of the traffic along the southern coast.

The last group of ships (“all other vessels”) is dominated by fishing vessels going to the fishing fields and mostly to Norwegian fishing ports for further export by ship, road or air.

6.2 The parts of the route

The traffic forecast for the whole fairway, i.e. from Røst to the Oslo fjord, is split geographically into six sections due to the differing traffic developments expected. Sections 1-3 are relevant for the present study, whereas sections 4-6 are relevant for the study of the effects of the routeing measure between Røst and Utsira which is presented in a separate report (Akhtar & Jean-Hansen 2009). The six geographical sections are:

1. From the Swedish border to Brevik (the VTS centre where the fairway into Grenland port in Telemark County is located)
2. From Brevik to Lindesnes (Lindesnes is the southernmost point of the Norwegian mainland in Vest-Agder County)
3. From Lindesnes to Fedje in Hordaland County (Fedje is in the middle of the western coast, approximately 50 km north of Bergen)
4. From Fedje to Stad in Møre and Romsdal County (Stad is the northwesternmost point of southern Norway and a spot with particularly hard winds and rough sea most of the year)
5. From Stad to Rørvik (Rørvik is a small port north of the Trondheim fjord and an important port used by Hurtigruten)
6. From Rørvik to Røst (Røst is a small inhabited island just outside the waters of Lofoten in Nordland County).

Figure 6.1 gives a picture of the profile of the present ship traffic on parts of the fairway. These six registration points depicted in figure 6 are all located between Lindesnes and Stad, i.e. in the geographical sections 3 and 4 in the list given above. Måløy is close to Stad (the northwesternmost point), whereas Farsund is close to Lindesnes (the southernmost point). Thus the six registration points give a picture of the ship traffic along the west coast of Norway.

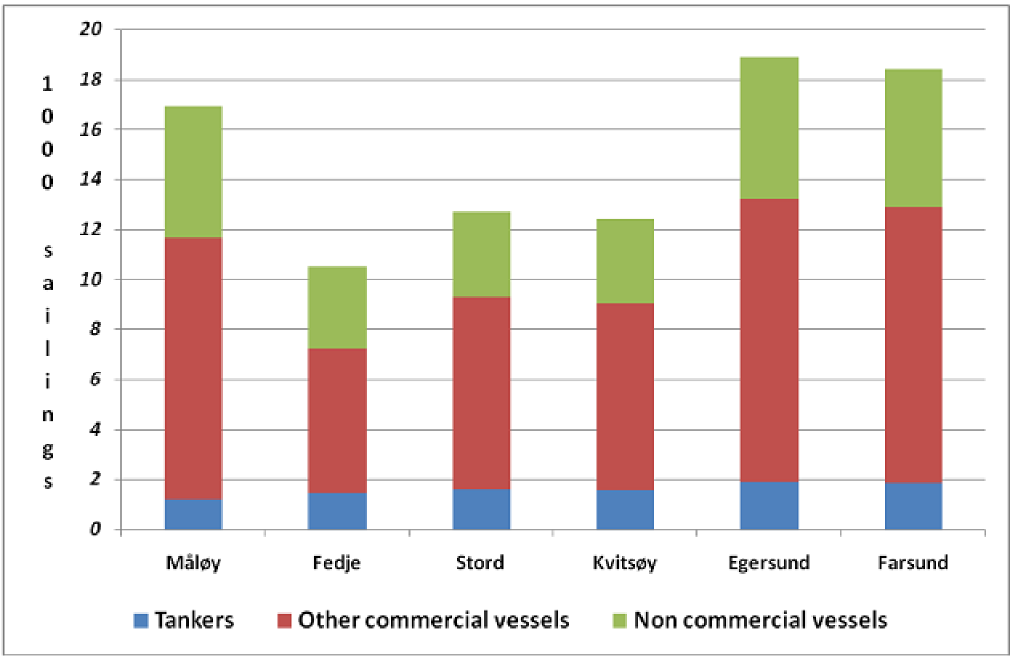


Figure 6.1 The number of sailings per year for ships and vessels distributed ship types and geographical registration points on the Norwegian west coast. Source: Safetec (2007).

The ship traffic volume differs along the western coast according to figure 6.1. The southernmost registration points, i.e. Egersund and Farsund, have the largest amount of traffic, but also by Måløy there are relatively large traffic volumes. It is also clear from figure 6.1 that "Other commercial vessels" (cargo ships) constitute the major part of the ship traffic passing through the registration points on the Norwegian west coast. Non-commercial traffic constitutes between 27 and 31 per cent of all sailings. The number of tankers passing is substantially lower, and fairly stable between the registration points. There is however a slight increase in the number of tankers from the left-hand to the right-hand side in the figure, implying that the number of tankers increases the further south we go.

6.3 Traffic forecasts by type of ship

By utilizing the traffic data from the registration points given in figure 6.1 and by analyzing the oil and gas shipments plan from the NCA and from internationally published reports, a traffic forecast for 2025 was developed for various sections of the route. The forecast was divided into two, one for tankers and one for non-tankers larger than 5000 GT (i.e. cargo vessels). The forecast for cargo vessels for sections 1, 2 and 3 of the fairway between the Swedish border and Utsira is given in figure 6.2.

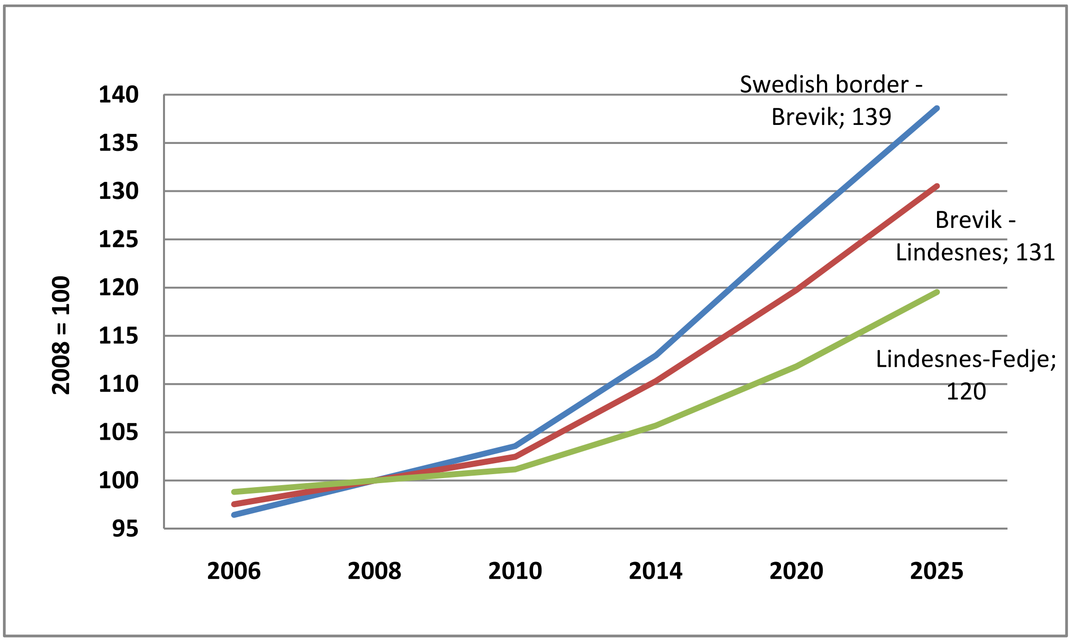


Figure 6.2 Traffic forecasts for cargo vessels on various geographical sections along the Norwegian coast, from 2006 to 2025. Index, 2008=100. Source: Hovi & Madslien (2009).

According to the forecasts given in figure 6.2 traffic volumes for cargo vessels will increase on all three sections of the route. Cargo vessel traffic is however expected to increase more on the east coast from the Swedish border to Brevik and on the south-east coast from Brevik to Lindesnes than from Lindesnes to Fedje.

The tanker traffic in this area is dominated by tankers to and from the North Sea and by product tankers (smaller tankers) serving the domestic market in Norway as well as by oil and gas tankers to and from the Norwegian refineries.

For crossing lanes we have assumed a larger increase in the number of sailings with LPGs compared to oil tankers. The reason is that we expect an increase in household gas consumption compared to oil consumption, because gas is more environmentally friendly and clean. In addition, gas is easily available and cheap for the populations of the North Sea countries.

The traffic to and from the offshore fields in the North Sea is not expected to increase. Tanker traffic to and Norwegian and Swedish ports (refineries) and product tankers with refined products to ports (depots) are, however, expected to grow due to the expected increased gas and oil consumption. Most of the product tankers are smaller tankers, but some of the tankers going to and from the Norwegian refineries are large tankers. Traffic forecasts for oil and gas tankers are given in figure 6.3

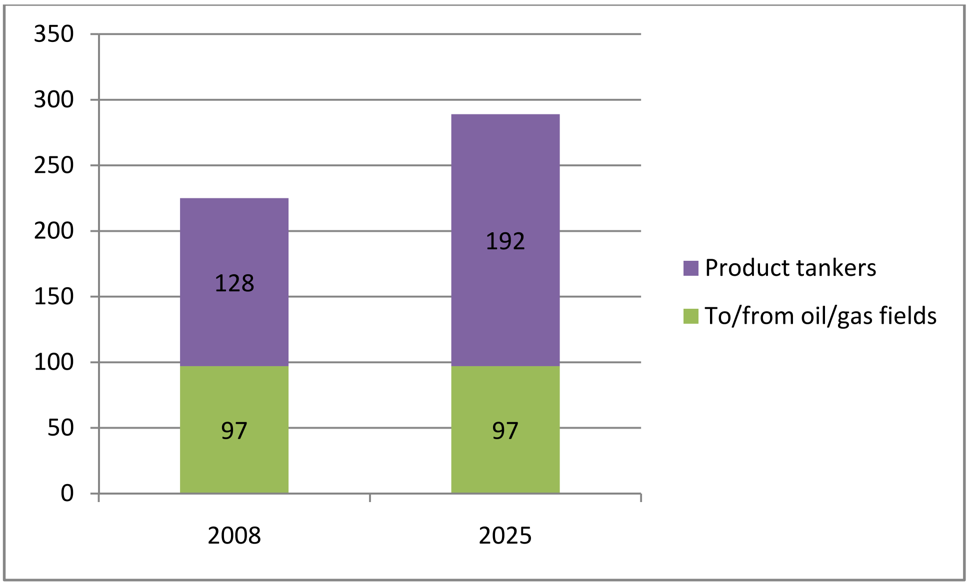


Figure 6.3 The actual and expected number of sailings of tankers on the south coast (Utsira-Oslo fjord) of Norway in 2008 and 2025. Source: The Norwegian Petroleum Directorate and TØI.

According to figure 6.3 one can expect a substantial increase in product tanker traffic (notably gas tankers) on the south coast, whereas the tanker traffic to and from the oil fields in the North Sea is expected to remain stable.

Table 6.1 gives the traffic volume data for today's routes and the proposed route both for 2008 and 2025 distributed by type of ship. The numbers are aggregated per ship type by MARCS. These traffic figures are used as the basis for the risk calculations presented later in the report.

Table 6.1 The total traffic volume (in 1000 nautical miles) in 2008 and 2025 distributed by type of ship on today's routes and on the proposed route.

	Today's routes 2008	Proposed route 2008	Today's routes 2025	Proposed route 2025
Chemical Tanker	371	546	536	763
Gas Tanker	217	301	961	1360
Oil Tanker	172	244	247	456
Cargo ships >5000 GT	496	828	600	1020
Other ships >5000 GT	197	313	238	375
All other vessels	1980	2030	1810	1850
Total	3430	4260	4390	5830

Source: DNV: In TØI-report 1037/2009, Appendix 10

According to table 6.1 implementing the proposed route will increase the traffic volume of all ship types, but only marginally for "all other vessels". These are predominantly fishing vessels. The forecast for 2025 reveals a substantial increase in the traffic volume of tankers, notably gas tankers, corresponding to the picture given in figure 6.3. Traffic volumes of "all other vessels" are expected to decrease in the future, due to an expected decrease in the number of fishing vessels.

6.4 Total traffic forecasts

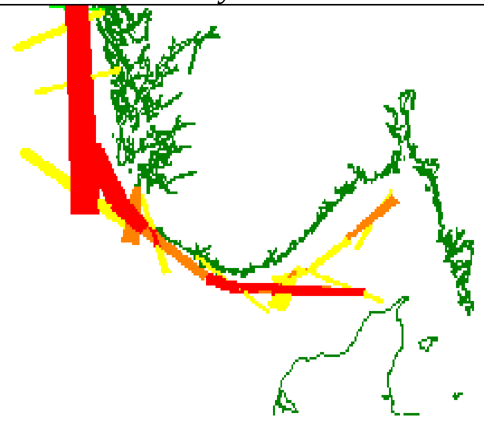
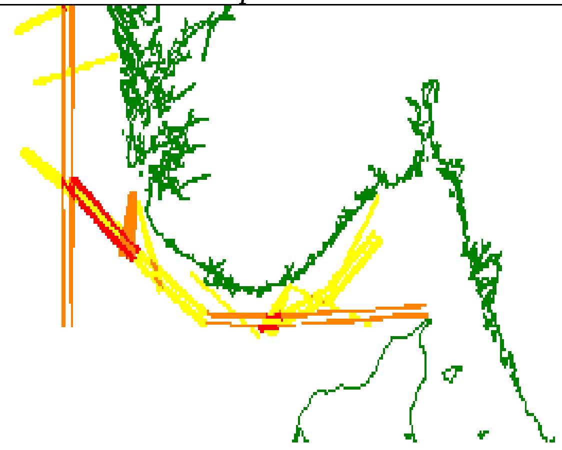
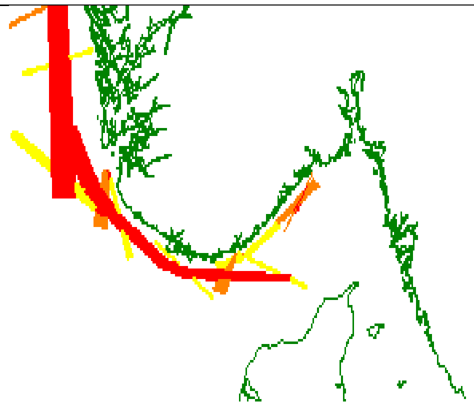
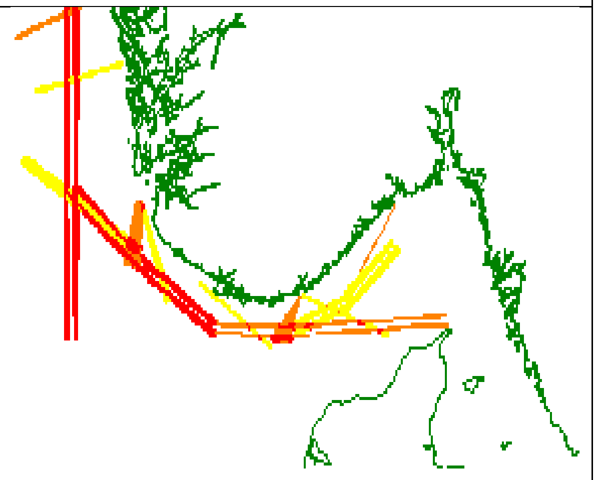
Using the forecasts for various sections and ship types, we have estimated the total traffic volumes on the entire route as of the year 2025. The expected ship traffic volumes are visualized in figures 6.4 and 6.5. Table 6.2 shows the keys for reading these plots. Vessels smaller than 5000 GT have been excluded from the diagrams, but they are of course included in the simulation results.

Table 6.2. lists the colours used in the traffic plots. Red colour indicates dense traffic with over 10 movements per day, while green, blue and grey colours indicate low levels of traffic. Yellow colour indicates traffic of 1-5 movements per day while orange indicates 5-10 movements per day.

Table 6.2 Key to Ship Traffic Plots

Colour	Traffic frequency (ship movements per day within each location)
(grey)	0.05 to 0.1
(cyan)	0.1 to 0.5
(green)	0.5 to 1
(yellow)	1 to 5
(orange)	5 to 10
(red)	> 10

Source: DNV: In TØI-report 1037/2009, Appendix 10

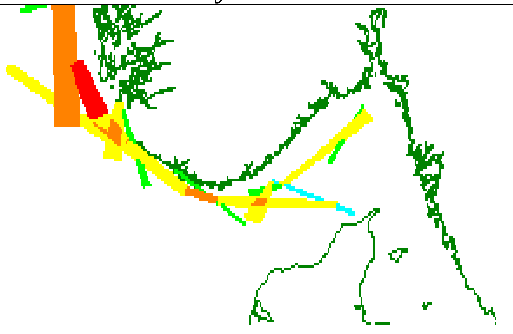
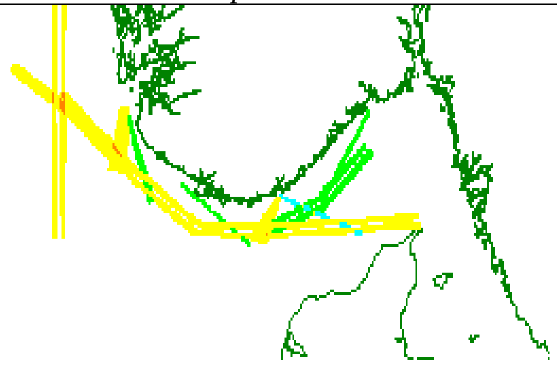
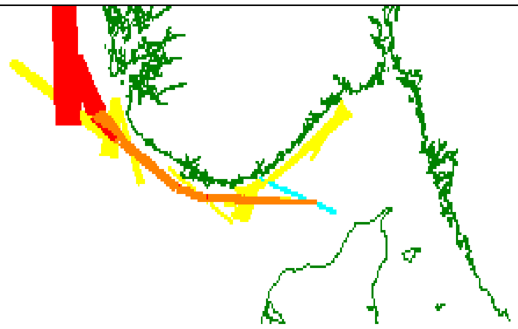
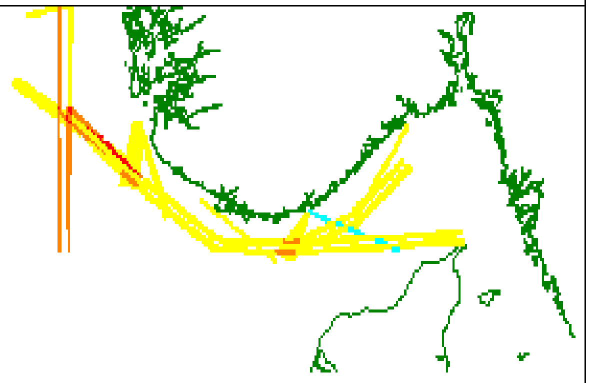
	Traffic plots for all traffic >5000 GT	
Year	Today's routes	Proposed route
08		
25		

Source: DNV: In TØI-report 1037/2009, Appendix 10

Figure 6.4 Traffic plots for all vessels above 5000 GT in 2008 and 2025 on today's route and on the proposed route. Today's traffic (2008) is given in the top left diagram; estimated traffic on the proposed route in 2008 is given in top right diagram; forecast for 2025 on today's routes is given in the bottom left diagram and on the proposed route in the bottom bottom right diagram.

The plots clearly show that the proposed new route directs the traffic farther away from the coast. The plots also visualize how the proposed new route segregates ships moving in different directions. The proposed route seems more lucid with fewer crossings and accordingly lower probability of collisions. Fewer crossings may also make ship crews more alert at each crossing and thereby reduce collision probabilities even more. This possible increase in alertness is, however, not included in our simulation.

Tankers are of particular interest in this study due to their high potential of oil spills. Figure 6.5 gives traffic plots for oil and chemical tankers alone in a fashion similar to figure 6.4.

	Traffic plots for Oil and Chemical tankers	
Year	*Today`s routes*	*Proposed route*
08		
25		

Source: DNV: In TØI-report 1037/2009, Appendix 10

Figure 6.5 Traffic plots for oil and chemical tankers in 2008 and 2025 on today's route and on the proposed route. Today's traffic (2008) is given in the top left diagram; estimated traffic on the proposed route in 2008 is given in top right diagram; forecast for 2025 on today's routes is given in the bottom left diagram and on the proposed route in the bottom right diagram.

Figure 6.5 reveals that tanker traffic will increase substantially and large parts of the coast will have more than 10 tanker movements per day in 2025. The plots reveal that on today's routes the tanker traffic will go quite close to the coast. The proposed route moves the traffic farther away from the coast and with the traffic separation schemes adopted the proposed new route seems to cope with the increased tanker traffic reasonably well.

7 Accident and oil spill probabilities

7.1 Scope of the study

In the following, accident probability figures will be calculated both for today's routes and for the proposed new route, relying on historical accident data and on the traffic forecasts given above.

In order to estimate the expected number of accidents and oil spills for the two routes, DNV was engaged to perform probability calculations based on the MARCS model. The Institute of Transport Economics (TØI) was responsible for input data quality and for the interpretation of the results. Shipping patterns and other input data characteristics of shipping operations in the year 2008 have been extrapolated to the year 2025 by TØI.

The calculations are restricted to accidents affecting the marine environment, while accidents in port approach and port areas are excluded from the scope of this work. The accident and oil spill calculations are confined to the release of the following materials due to accidental events:

- Crude oil and refined products carried as cargo by tankers.
- Bunker fuel oil carried by all ships.

In addition to the accident and oil spill probabilities presented in this chapter, two separate oil spill case scenarios have been developed by Norconsult for accidents at two separate locations along the coast: Egersund and Ryvingen. The results from these scenarios are described in chapter 8 and presented in detail in Appendix 8

7.2 Description of the MARCS model

MARCS was developed by DNV to support their marine risk management consultancy business. The MARCS model provides a general framework for the performance of marine risk calculations. A block diagram of the model is shown in figure 7.1.

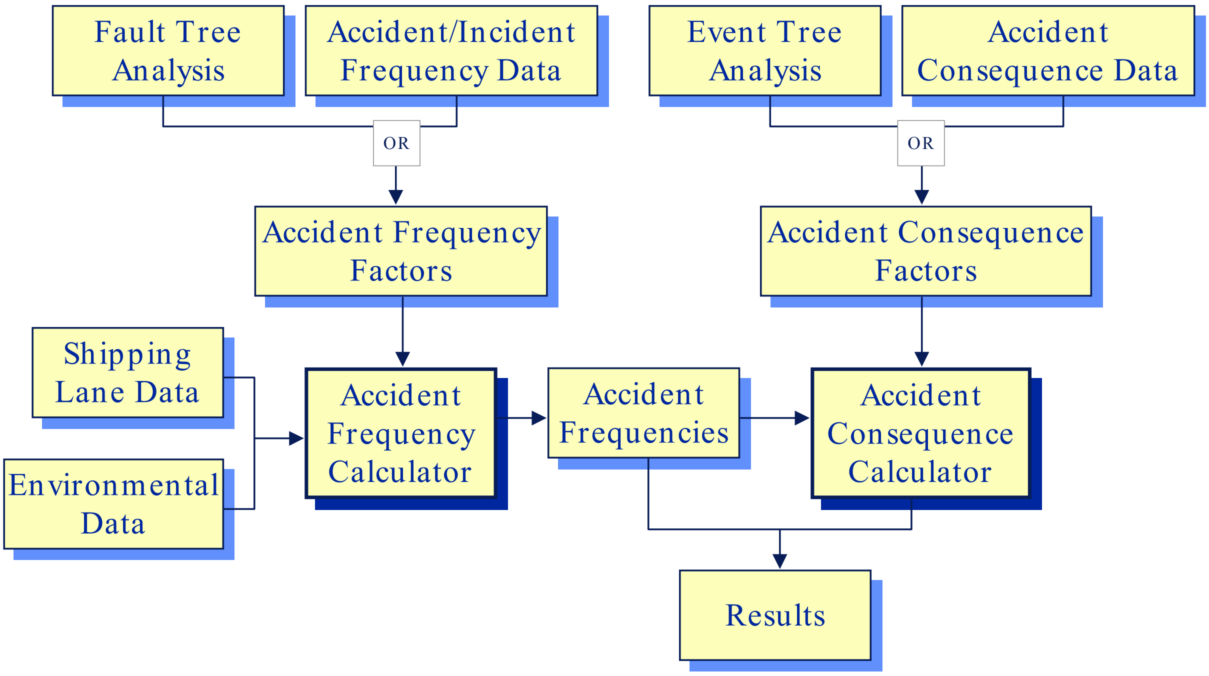


Figure 7.1 Block diagram of MARCS Source: DNV Appendix 4

The MARCS model classifies data into 4 main types:

- Shipping lane data describes the movements of various marine traffic types within the study area;
- Environment data describes the conditions within the calculation area, including the location of geographical features (land, offshore structures etc.) and meteorological data (visibility, wind rose, currents and sea state);
- Internal operational data describes operational procedures and equipment installed onboard ship – such data can affect both accident frequency and accident consequence factors;
- External operational data describes factors external to the ship that can affect ship safety, such as VTMS (Vessel Traffic Management Systems), TSS (Traffic Separation Schemes), and the location and performance of emergency tugs – such data can affect both accident frequency and accident consequence factors.

As indicated in figure 7.1, accident frequency and consequence factors can be derived in two ways. If a coarse assessment of accident risk is required, the factors may be taken from worldwide historical accident data. Alternatively, if a more detailed study is required, these factors may be derived from generic fault trees or event trees which have been modified to take account of specific local factors, as in our case.

7.3 Data input

A range of data sets are used by MARCS to simulate the traffic, the various accidents frequencies and the oil spills. A brief summary of the type of data input entered into the model will be described in this chapter. More details of these data can be found in Appendix 5.

7.3.1 Traffic image data

The marine traffic image data used by MARCS is a representation of the actual flows of traffic within the calculation area. Marine traffic data are represented through lane data structures. Various traffic types are divided into separate marine data bases in order to facilitate data verification and the computation of various types of risk (for example, crude oil spill risk versus human safety).

7.3.2 Internal operational data

Internal operational data are represented within MARCS using location specific survey data. Examples of internal operational data include:

- The probability of a collision given an encounter;
- The probability of a powered grounding given that a ship's course is close to the shoreline;
- The frequency (per hour at risk) of fires or explosions.

7.3.3 External operational data

External operational data generally represent controls external to the traffic image, which affect marine risk. In MARCS they relate mainly to the location of VTS zones (which influence the collision and powered grounding frequencies by external vigilance, where external vigilance means that an observer external to the ship may alert the ship to prevent an accident), and to the presence and performance of emergency towing vessels (tugs) which can save a ship from drift grounding.

7.3.4 Wind rose and sea state data

The severity of the North Sea weather is well known. A noteworthy characteristic is the seasonal and year-to-year variations. An accurate estimation of the wind climatology must therefore be based upon long time series of high-quality wind data.

Wind rose data is defined within 8 compass points (north, north-east, east etc.) in 4 wind speed categories: 1) calm (0 to 20 knots); 2) fresh (20 to 30 knots); 3) gale (30 to 45 knots); and 4) storm (greater than 45 knots). Sea state (wave height) within MARCS is inferred from the wind speed and the nature of the sea area (classified as sheltered, semi-sheltered or open water).

To simplify our simulation in relation to wind, four wind states were defined as shown in table 7.1. The sea state or the wave height is determined from a combination of the wind speed and the nature of the sea area, i.e. if the water is open, semi-sheltered or sheltered. For our study the routes were naturally defined as open waters (cf. Appendix 5 for details).

Table 7.1 Wind states and corresponding sea states

Wind state	Sea state
Calm	Flat – Moderate waves of some length.
Fresh	Long waves begin to form – Sea heaps up
Gale	Moderately high waves with breaking crests forming spindrift
Storm	Very high waves with overhanging crests – huge waves. Sea is completely white with foam and spray.

7.3.5 Visibility

Poor visibility arises when fog, snow, rain or other phenomena restrict visibility to less than two nautical miles. It should be noted that night-time is categorized as good visibility unless restricted by fog, snow etc.

Visibility data was provided by the Norwegian Meteorological Institute (Met.no). On average, from 1971 to 2000, the winter months from December to March are those with poorest visibility. In this period, visibility along the coast is categorized as good (defined as range of vision of 10 km) 80 per cent of the time. Visibility is best during May to September, with good visibility 90 % of the time.

Visibility between 4 and 10 kms is rare for this coast line. The visibility assumptions entered into MARCS was that visibility was better than 4 km 95% of the time and poorer than 4 km 5 % of the time all year round.

7.3.6 Hazards

Analyses of historical ship accident data indicate that almost all open-water shipping losses (excepting causes such as war or piracy) can be categorized into seven generic accident types as listed in table 7.2. (The table also gives the abbreviations used in the simulation. These will be useful for reading the detail statistics in Appendix 6.)

Table 7.2 Generic ship accident types

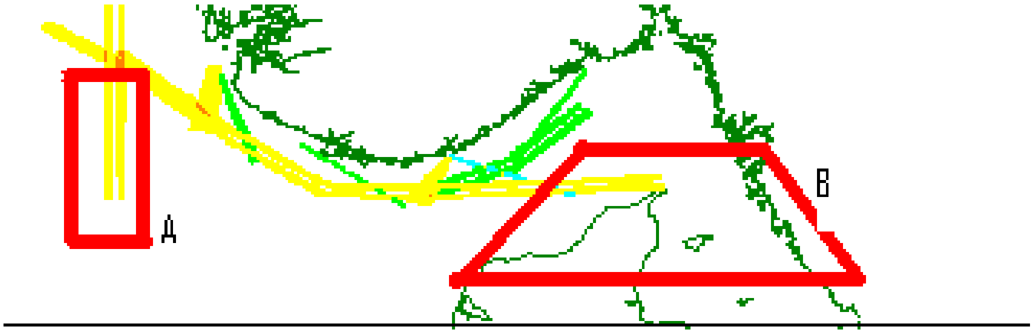
Accident type	Abbreviation
Ship-ship collision	Collis
Powered grounding (groundings which occur when the ship has the ability to navigate safely yet goes aground, such as the *Exxon Valdez*):	PGrd
Drift grounding (groundings which occur when the ship is unable to navigate safely due to mechanical failure, such as the *Braer*):	DGrd
Structural failure/foundering whilst underway	Struc
Fire/explosion whilst underway	Fex
Powered ship collision with fixed marine structures such as platforms or wind turbines (similar definition to powered grounding):	PPlat
Drifting ship collision with fixed marine structures such as platforms or wind turbines (similar definition to drift grounding)	DPlat

Source: DNV: In TØI-report 1037/2009, Appendix 10

These generic accident types effectively represent the results of a high level marine transportation hazard identification (HAZID) exercise and are applicable for most marine transportation systems. DNV considers this high level HAZID to be sufficient for the risk calculations in this project.

7.3.7 Comparing today's route with the proposed new route

To get comparable results, the old routes and the new route must cover similar areas. As can be seen from the traffic plots given in figures 6.3 and 6.4 the proposed new route is defined as stretching farther south and farther east than today's routes. In order to compare the old routes with the proposed new route with respect to accident and oil spill frequencies, it is necessary to have the same areas covered by the two alternatives. Thus, in the accident and oil spill simulations we have excluded traffic of the parts of the proposed new route that do not have corresponding traffic on today's routes. The excluded parts of the routes are denoted as area A and B and depicted in figure 7.2.



Source: TØI-report 1037/2009

Figure 7.2 The proposed new route Utsira-Oslo fjord with tanker traffic volumes of 2008. Areas A and B are parts of the proposed new route that are excluded from the estimations of accident and oil spill probabilities due to lack of corresponding traffic data for today's routes.

7.4 Accident analyses

In the following we present three types of figures on expected numbers of accidents:

1. Expected accident frequencies (accidents per year) by ship and accident type, for today's routes and the proposed new route in 2008.
2. Expected spill accident frequencies (cargo and bunker oil spills) by ship type for today's route and the proposed new route in 2008 and 2025
3. Expected oil spill volumes (cargo and bunker oil spills) by ship type for today's route and the proposed new route in 2008 and 2025

7.4.1 Accident frequencies in 2008

Tables 7.3 and 7.4 presents the expected accident frequency per year given traffic volumes and ship type distributions of 2008 for the routes travelled today and for the proposed new route. The accident figures are also distributed according to accident and ship types.

Table 7.3 Expected accident frequency per year in 2008. Today's routes Utsira-Oslo fjord.

	Total	Chemical Tanker	Gas Tanker	Oil Tanker	Cargo > 5000 GT	Other vessels >5000 GT	Rest
Collis	**0.223**	0.024	0.014	0.011	0.032	0.013	0.129
Struc	**0.132**	0.014	0.008	0.007	0.019	0.008	0.077
FEX	**0.116**	0.012	0.007	0.006	0.017	0.007	0.067
PGrd	**0.572**	0.072	0.043	0.036	0.125	0.083	0.213
DGrd	**4.050**	0.414	0.269	0.144	0.568	0.215	2.440
PPlat	**0.000**	0.000	0.000	0.000	0.000	0.000	0.000
DPlat	**0.000**	0.000	0.000	0.000	0.000	0.000	0.000
Total	**5.100**	0.537	0.343	0.203	0.761	0.325	2.930

Source:TØI-report 1037/2009 (Appendix 6: MARCS results)

Table 7.4 Expected accident frequency per year in 2008. Proposed route Utsira-Oslo fjord.

	Total	Chemical Tanker	Gas Tanker	Oil Tanker	Cargo > 5000 GT	Other vessels >5000 GT	Rest
Collis	**0.182**	0.015	0.010	0.007	0.028	0.010	0.113
Struc	**0.142**	0.016	0.009	0.007	0.025	0.009	0.076
FEX	**0.124**	0.014	0.008	0.006	0.022	0.008	0.067
PGrd	**0.552**	0.066	0.040	0.034	0.118	0.080	0.213
DGrd	**3.420**	0.225	0.156	0.079	0.366	0.143	2.450
PPlat	**0.000**	0.000	0.000	0.000	0.000	0.000	0.000
DPlat	**0.002**	0.001	0.000	0.000	0.001	0.000	0.000
Total	**4.420**	0.336	0.224	0.133	0.561	0.250	2.920

Source: TØI-report 1037/2009 (Appendix 6: MARCS results)

In total, 5.1 accidents are expected to take place in 2008 on today's routes. The estimated figure if the proposed new route is implemented, is 4.4 accidents. There is a an expected reduction in all types of accidents except accident types Struc (Structural failure/foundering whilst underway) and Fex (Fire/explosion whilst underway). The reason why these accident types increase slightly is that the proposed new route is longer and consequently the time at sea is increased

According to table 7.3 and 7.4, drift grounding accidents are those that will be most reduced by imposing the new route; from 4.0 to 3.4. This is hardly surprising since the routing scheme moves the ship traffic farther away from the shore.

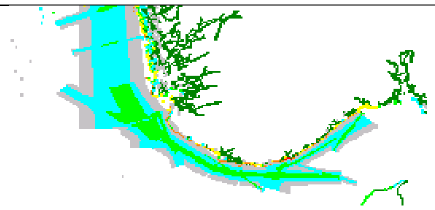
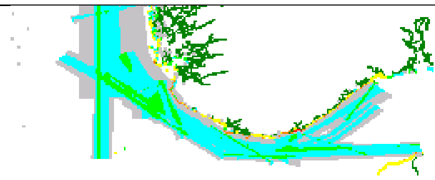
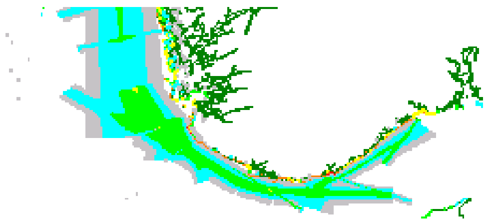
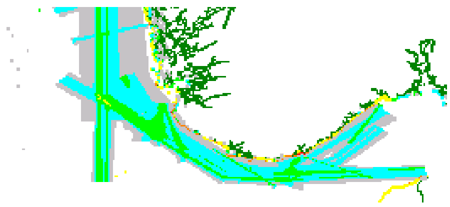
7.4.2 Expected spill accident frequencies in 2008 and 2025

Not all accidents result in oil spills. Figure 7.3 presents plots of the expected bunker oil spill accidents plus cargo spill accidents for chemical tankers and oil tankers on today's route and on the proposed route in 2008 and 2025. Details can be found in Appendix 6. Table 7.5 explains the colour code used in the plot. As in the plots presented above, today's routes are presented on the left-hand side and the proposed new route on the right-hand side.

Table 7.5 Key to accident frequency plots

Colour	**Accident frequency (accidents per year within each calculation location)**
	1.0 E-08 - 1.0 E-06
	1.0 E-06 - 1.0 E-05
	1.0 E-05 - 1.0 E-04
	1.0 E-04 - 1.0 E-03
	1.0 E-03 - 1.0 E-02
	> 1.0 E-02

Source: DNV: In TØI-report 1037/2009, Appendix 10

	Spill accidents: Bunker spill from all traffic plus cargo oil spill from chemical tankers and oil tankers	
Year	*Today`s routes*	*Proposed route*
08		
25		

Source: DNV: In TØI-report 1037/2009, Appendix 10

Figure 7.3 Expected frequencies of spill accidents: bunker and cargo oil spills on today's route and the proposed new route in 2008 and 2025. The accidents for today's routes/2008 is given in the top left diagram; the proposed new route/2008 in the top right diagram; the accidents for today's routes in 2025 is presented in the bottom left diagram and for the proposed route in the bottom right diagram.

The plots given in figure 7.3 indicate that there will be a reduction of spill accidents if the proposed new route is adopted (indicated by a smaller green coloured area in the plots of the proposed route). By merely looking at the plots it is however difficult to draw any clear conclusions about expected oil spill frequencies of redirecting ship traffic to the proposed new route. This is however revealed in table 7.6, which gives the total spill accident frequencies distributed by vessel types for the four scenarios depicted in figure 7.2.

Table 7.6 Spill accident frequencies for today's route and for the proposed route in 2008 and 2025 distributed by ship type. Utsira-Oslo fjord.

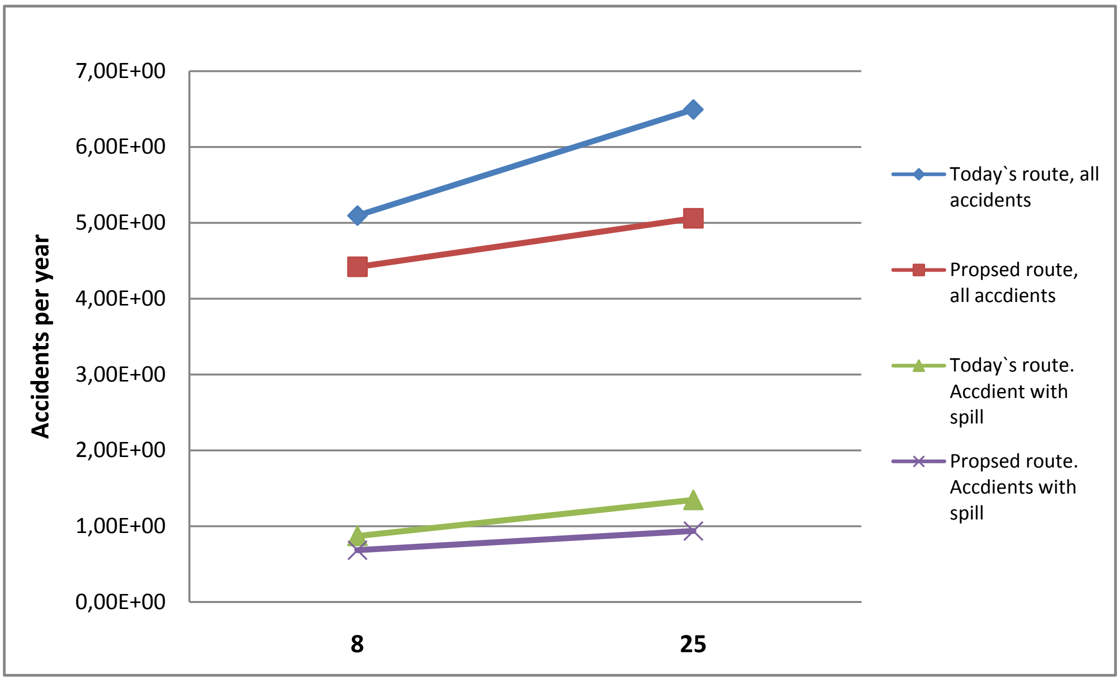
	Total	Chemical Tanker	Gas Tanker	Oil Tanker	Cargo > 5000 GT	Other vessels >5000 GT	Rest
Today's routes 2008	**0.87**	0.25	0.13	0.09	0.08	0.03	0.29
Proposed route 2008	**0.68**	0.16	0.09	0.06	0.06	0.03	0.29
Today's routes 2025	**1.35**	0.37	0.44	0.14	0.09	0.04	0.27
Proposed route 2025	**0.98**	0.24	0.23	0.10	0.07	0.03	0.27

Source: TØI-report 1037/2009 (Appendix 6: MARCS results)

Table 7.6 clearly shows that the expected number of spill accidents is decreased when adopting the proposed new route. This is true both for the total number of accidents and for the accidents for each of the different ship types.

The vessels in the category "Rest" will not follow the proposed new route, and thus the changes in accident probabilities are small. The small reduction can be attributed to the fact that when other vessels are rerouted, the vessels in the "Rest" category have fewer other vessels to collide with.

Figure 7.4 gives a picture of the expected accident frequencies both for all accidents and for oil spill accidents for today's route and for the proposed new route, in 2008 as well as in 2025.



Source: TØI-report 1037/2009

Figure 7.4 Effects on all accidents and on oil spill accidents for the present route and for the proposed new route in 2008 and 2025

The expected number of accidents both with and without oil spills is lower for the proposed new route both in 2008 and 2025, but the difference for oil spill accidents is rather moderate and less than for all accidents. However, when, in the next section, we compare the two alternative routes with respect to the expected oil spill volumes, the picture is altered and the proposed new route is seen to have a substantial beneficial effect.

7.4.3 Expected oil spill volumes in 2008 and 2025

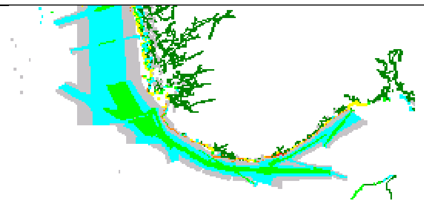
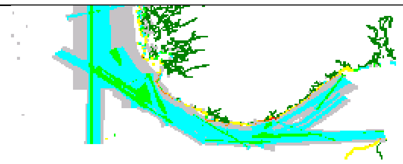
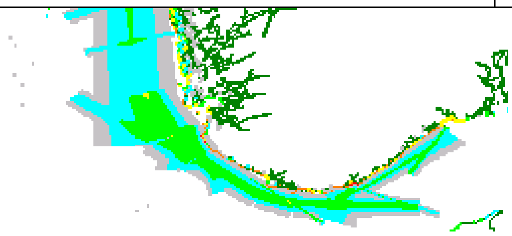
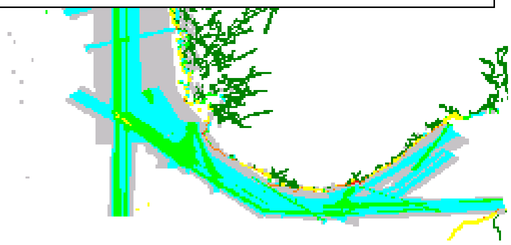
Not all accidents are spill accidents, and not all spill accidents lead to huge oil spills. The cargo and bunker fuel oil risks (average tonnes of oil lost from containment per year) depend on ship type and accident type. Figure 7.4 presents plots of the expected cargo oil spill volumes for chemical tankers and oil tankers on today's route and on the proposed new route in 2008 and 2025.

Details are presented in Appendix 6. Table 7.7 explains the colour code used in the plot. As in the plots previously presented, today's routes are presented on the left-hand side and the proposed new route on the right-hand side of figure 7.5.

Table 7.7 Key to accident risk plots

Colour	Cargo spill risk (tonnes cargo spilt per year within each location)
(grey)	1.0 E-06 – 1.0 E-05
(cyan)	1.0 E-05 – 1.0 E-04
(green)	1.0 E-04 – 1.0 E-02
(yellow)	1.0 E-02 – 1.0 E-01
(orange)	1.0 E-01 – 1.0
(red)	> 1.0

Source: DNV: In TØI-report 1037/2009, Appendix 10

	Bunker oil spill from all traffic types and cargo oil spill from Chemical tankers and Oil tankers	
Year	*Today`s routes*	*Proposed route*
08		
25		

Source: DNV: In TØI-report 1037/2009, Appendix 10

Figure 7.5 Bunker and cargo oil spills in 2008 and 2025 for today's route and for the proposed new route. The spills for today's route/2008 is given in the top left diagram; the proposed new route/2008 in the top right quadrant; the spills for today's route in 2025 is presented in the bottom left diagram and for the proposed route in the bottom right diagram.

The plots given in figure 7.5 indicate that there will be a substantial reduction of oil spill volumes if the proposed new route is adopted. Overall, it is clear that with the proposed new route, the oil spill will be concentrated within the lanes, and the oil spill in the rest of the sea and on the shore will lowered. Detailed oil spill figures are given in table 7.8.

Table 7.8 Expected oil spills in tonnes per year on the fairway Utsira-Oslo fjord for today's routes and the proposed route distributed by ship types and traffic estimates for 2008 and 2025.

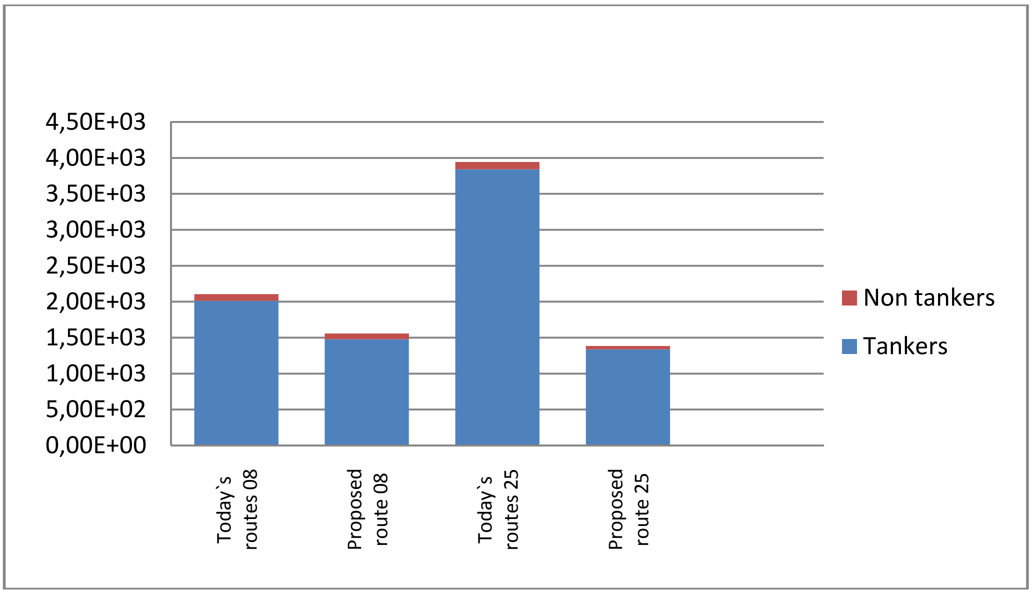
	Total	Chemical Tanker	Gas Tanker	Oil Tanker	Cargo > 5000 GT	Other >5000 GT	Rest
Today's routes 2008	2105.6	586.3	361.2	1065.5	52.2	6.7	33.7
Proposed route 2008	1557.4	412.1	242.3	822.8	41.2	5.4	33.7
Today's routes 2025	3944.6	863.9	1400.3	1576.9	64.0	8.2	31.3
Proposed route 2025	1383.2	313.2	345.1	679.6	26.4	3.3	15.6

Source: TØI-report 1037/2009 (Appendix 6: MARCS results)

It is clear that the oil spill probability is reduced for all vessel types for both traffic scenarios by adopting the proposed route. In total, the proposed routing is expected to reduce oil spills by 548 tonnes per year in 2008 and by 2561 tonnes in 2025. The main reason for this substantial reduction is that the number of groundings is reduced. The reduction is particularly strong for tankers. More detailed analyses of tankers are presented in section 7.4.4.

7.4.4 Expected accident frequencies and oil spill volumes for tankers

Tankers are of particular interest in the present study because they contribute to the vast majority of oil spills. Tankers include oil tankers, chemical tankers and gas tankers. For tankers the proposed new route has particularly beneficial effects. One important reason for this is that grounding accidents are reduced as seen in table 7.3/7.4. Figure 7.6 presents the expected oil spill volumes that can be attributed to tankers and non-tankers on today's route and on the proposed new route in 2008 and 2025.



Source: TØI-report 1037/2009

Figure 7.6 Expected oil spill volumes from tankers and non-tankers in tonnes, including bunkers oil on today's route and the proposed route with traffic data for 2008 and 2025. Tankers include oil tankers, chemical tankers and gas tankers.

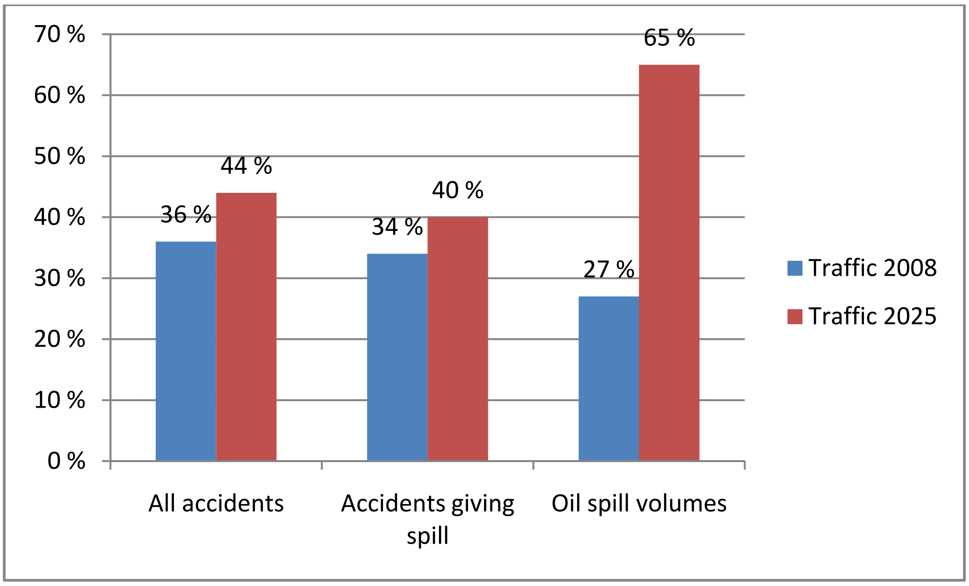
Figure 7.6 clearly reveals that tankers are responsible for almost all oil spills. Accordingly the effect of the proposed new route for tanker accidents and spills are of particular interest, and especially oil tankers and chemical tankers (gas tankers can only spill their bunkers oil).

It is also important to note that it is the expected oil spill *volumes* that are of particular interest, because the environmental risk follows from oil spills rather than from the accidents per se. Figure 7.7 and table 7.9 present the effects of applying the proposed new route on the expected number of tanker accidents, on the expected number of spill accidents for tankers, and on the expected oil spill volumes for tankers in 2008 and 2025.

Table 7.9 Effects of proposed routeing on the expected number of all tanker accidents, on oil spill accidents for tankers, and on the expected volume of oil spills for tankers, with traffic data for 2008 and 2025.

Tankers only	All accidents [freq. per year]	Spill Accidents [freq. per year]	Oil spill + bunkers oil [tonnes per year]
Today's routes 2008	1.08	0.47	2010
Proposed route 2008	0.69	0.31	1480
Difference	0.39	0.16	536
Significance	Not sig.	Not sig.	Significant
Today's routes 2025	2.45	0.94	3840
Proposed route 2025	1.37	0.57	1340
Difference	1.08	0.37	2500
Significance	Not sig.	Not sig.	Significant

Source: TØI-report 1037/2009



Source: TØI-report 1037/2009

Figure 7.7 Effects of proposed routeing on the expected number of all tanker accidents, on oil spill accidents for tankers, and on the expected volume of oil spills for tankers, with traffic data for 2008 and 2025.

The proposed new route reduces both the expected number of accidents and the expected oil spill volumes from tanker accidents. The effects on the expected oil spill volumes are statistically significant at the 5 % level. Details regarding the calculation of confidence intervals and significance levels can be found in Appendix 7. The effects on the oil spill volumes are especially large in 2025 due to the anticipated growth in tanker traffic.

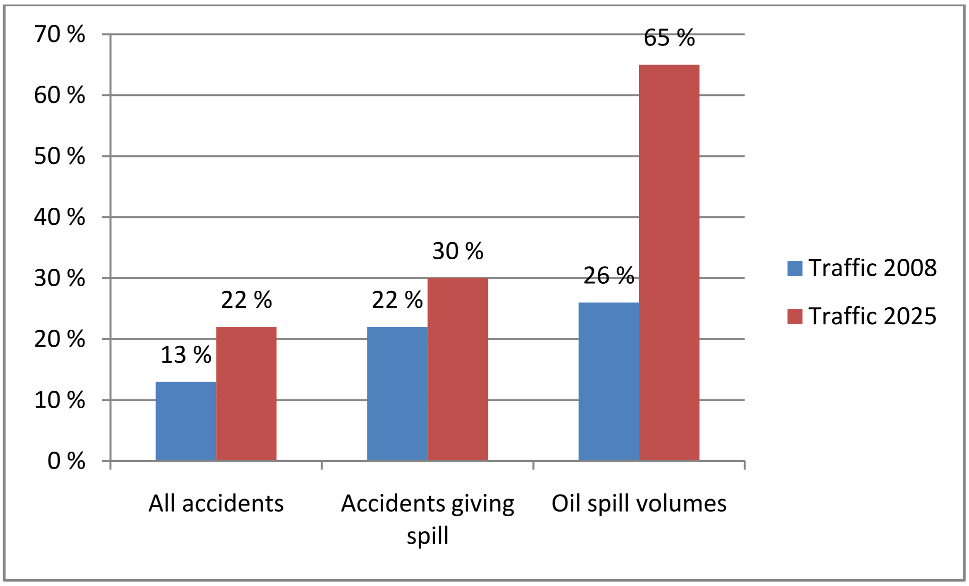
7.5 Aggregate results

The results given above reveal that adopting the proposed new route can be expected to reduce the number of tanker accidents and in particular the expected oil spill volumes. The effects are particularly strong for tanker accidents/spills. Figure 7.7 gives the aggregate effects for all ships (not only tankers) for the proposed new route compared with today's routes (for details see Appendix 6).

Table 7.10 Effects of proposed routeing on the expected number of all accidents, oil spill accidents, and on the expected volume of oil spills, with traffic data for 2008 and 2025.

All vessels	All accidents [freq. per year]	Spill Accidents [freq. per year]	Oil spill + bunkers oil [tonnes per year]
Today's routes 2008	5.10	0.87	2110
Proposed route 2008	4.42	0.68	1560
Difference	0.68	0.19	550
Significance	Not sig.	Not sig.	Significant
Today's routes 2025	6.45	1.35	3940
Proposed route 2025	5.06	0.94	1380
Difference	1.43	0.41	2560
Significance	Not sig.	Not sig.	Significant

Source: TØI-report 1037/2009



Source: TØI-report 1037/2009

Figure 7.8 Expected effects of proposed routeing on all accidents, oil spill accidents and the volume of oil spills with traffic data for 2008 and 2025.

Transferring ship traffic to the proposed new route gives a 13 per cent reduction in all accidents and a 22 per cent reduction in oil spill accidents given traffic volumes for 2008. When traffic forecasts for 2025 are used, the reductions are even larger. For oil spill volumes (both cargo and bunkers spills), there is a considerable effect of 65 per cent reduction when the proposed route is adopted with traffic data of 2025.

Another effect of the transfer of ship traffic to the proposed new route is that possible oil spills will occur farther away from the coast, giving the authorities more time to react and enable emergency towing or oil spill response that may significantly reduce the overall environmental impact, cf. the results of the two oil spill scenarios presented in Appendix 8.

However, when oil spills occur farther away from the coast a higher number of sites may be exposed to the spill. Experience shows nevertheless that the number of impact sites is not proportionate with the total impact area and may also be counterbalanced by the lower concentration of oil (severity of impact) on each site. During past oil spills it has been observed that oil tends to accumulate in patches. The extended drifting distance may decrease the impact intensity and hence ease the effect for the local populations within a region.

Summing up the results, it seems clear that implementing the proposed route for tankers and vessels above 5000 GT will lower probabilities for oil spills including bunkers oil spills and reduce the volumes of oil spills reaching the coast. Thus the proposed new route will significantly reduce the environmental impacts of the shipping traffic along the Norwegian coast.

8 Environmental impacts illustrated by two case scenarios - Egersund and Ryvingen

In this chapter we present two case scenarios of the environmental impacts of a major oil spill on the coast outside the two locations, Egersund and Ryvingen. Both are situated on the south coast of Norway. On both locations the consequences of a major oil spill are simulated for the proposed new route and for one of today's routes. To ensure comparable results, the scenarios at the locations are identical for the two routes except for the location of the spill accident. All estimations are conducted by use of identical simulation tool, input data and methodology. The scenarios were selected based on the following criteria:

- The national dimensioning oil spill scenarios defined by the Ministry of fisheries and coastal affairs
- AIS data and identification of high density traffic "hot spots"
- Potential threat to coastline and vulnerable marine resources
- Typical wind and sea current, and inside operational window for oil spill response

8.1 The accident probabilities at Egersund and Ryvingen

By running the MARCS simulation with the same assumptions as in chapter 7, but this time shrinking the study area to include only the areas around Egersund and Ryvingen, we obtain the expected number of spill accidents per year for the two locations. The results are shown in table 8.1.

For both scenarios it is evident that the expected number of spill accidents is considerably lowered for all vessel types. Egersund seems to have a higher spill accident frequency than Ryvingen, but the effect of introducing the proposed route is in the same magnitude for both locations. Also for both locations the favourable effect of the proposed route is larger when traffic forecasts for 2025 are used.

Table 8.1 Spill accident frequencies for today's routes and for the proposed route in 2008 and 2025 distributed by ship type for Egersund and Ryvingen.

		Total	Chemical Tanker	Gas Tanker	Oil Tanker	Cargo > 5000 GT	Other vessels >5000 GT
Egersund	**Today's routes 08**	**0.250**	0.0667	0.0340	0.0241	0.0241	0.0064
	Proposed route 08	**0.210**	0.0454	0.0257	0.0167	0.0216	0.0052
	Today's routes 25	**0.451**	0.1026	0.1866	0.0372	0.0295	0.0079
	Proposed route 25	**0.311**	0.0687	0.0918	0.0300	0.0274	0.0064
Ryvingen							
	Today's routes 08	**0.096**	0.0270	0.0093	0.0131	0.0084	0.0037
	Proposed route 08	**0.070**	0.0158	0.0052	0.0072	0.0052	0.0018
	Today's routes 25	**0.119**	0.0371	0.0168	0.0174	0.0105	0.0047
	Proposed route 25	**0.082**	0.0221	0.0085	0.0099	0.0065	0.0023

Source: TØI-report 1037/2009 (Appendix 9: Accident figures for the scenario areas)

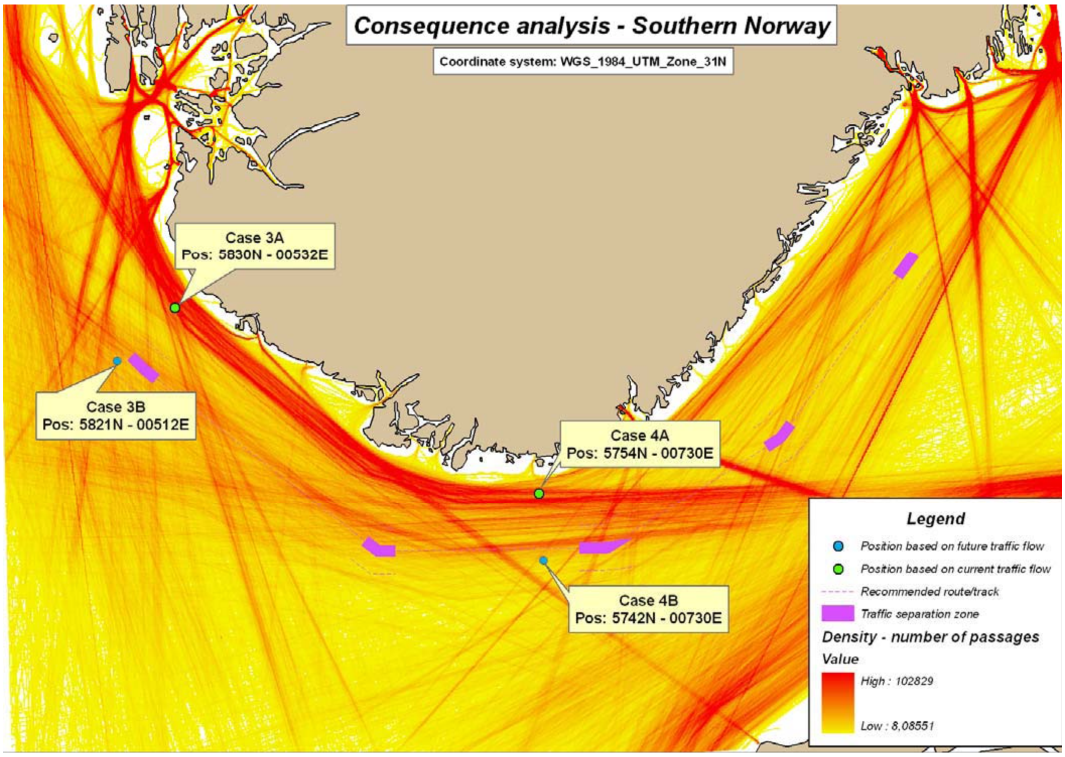
8.2 The scenarios

In the two case scenarios it is assumed that a collision takes place releasing oil into the sea. In the Egersund scenario it assumed to be 1000 m^3 bunker oil; in the Ryvingen scenario it is assumed to be 20 000 m^3 light crude oil. In the Egersund scenario the accident happens in spring; in the Ryvingen scenario the accident happens in autumn. The two case scenarios are described in detail in Appendix 8. Details about the assumptions etc. are also given in tables 8.2 and 8.3.

By using the oil drift simulation model developed by The Norwegian Meteorological Institute (DNMI), the *initial* shoreline impact length as well as the oil mass balance (evaporation, dispersion, on surface) has been calculated by NCA. Please note that the figures in this chapter show one dataset (time-step) only for comparison. Hour-by-hour simulation data has been utilized to obtain the results.

To assess the potential for emergency towing and preventing ship grounding (and spill), time from propulsion failure (at position A and B for each scenario) until grounding has been calculated and compared with tug boat response times.

The location of the case scenarios are given in figure 8.1.



Source: Norconsult: In TØI-report 1037/2009, Appendix 8

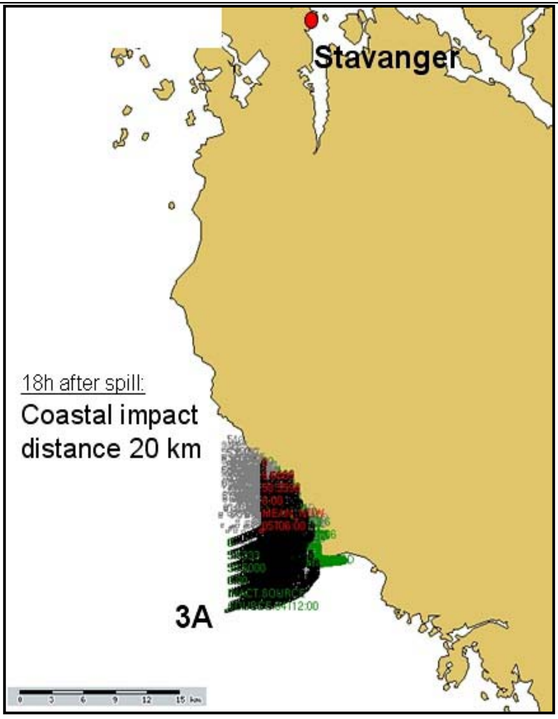
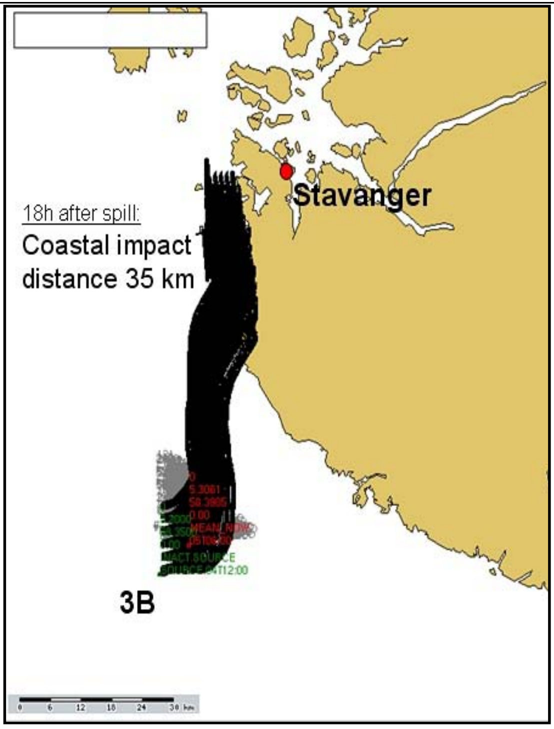
Figure 8.1 Location of the two scenarios where oil spill consequences are simulated. Case 3A and 4A are on today's routes; Case 3B and 4B are on the proposed route.

Table 8.2 and 8.3 presents the details of the simulations of accidents and consequences including type of incident, time of year, release type, oil type and release volumes. The tables also include the simulation results.

For the Egersund scenario, table 8.2 illustrates the oil drift consequences 18 hours after the accident. One major advantage of transferring ship traffic to the proposed route is the time increase for the oil to drift to shore. According to the simulations in this scenario the oil drifting time increases from 10 to 70 hours. Another advantage is that the oil volumes expected to reach the shoreline, given no oil spill response, are reduced from 998m^3 to 780 m^3 due to the fact that more oil is degraded in sea and air when time to impact increases. Another consequence of the oil spill accident being farther from the coast if the proposed route is adopted, is, however, that the size of the potential impact area increases, from 20 km to 35 km. Thus, according to the Egersund scenario, less oil will reach the shoreline, but the impact area is increased.

As the accident type, weather conditions and the amount of oil spilled are the same for today's route and the proposed route, we assume the costs of the ship loss, cargo, human lives and injuries to also be equal for today's route and the proposed route. These costs are therefore not include in our comparison.

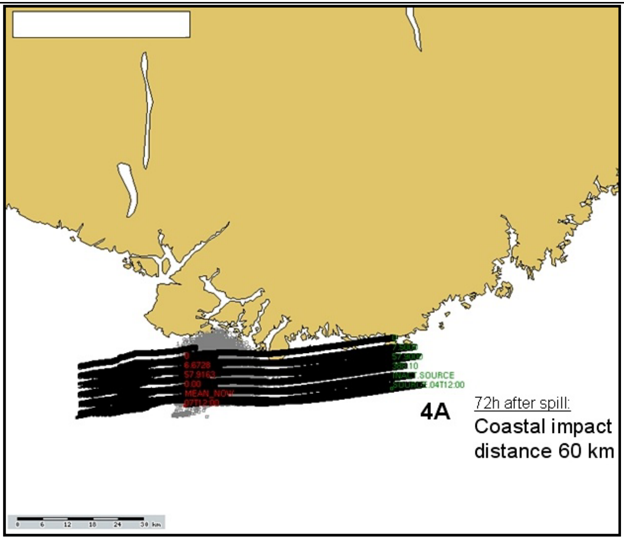
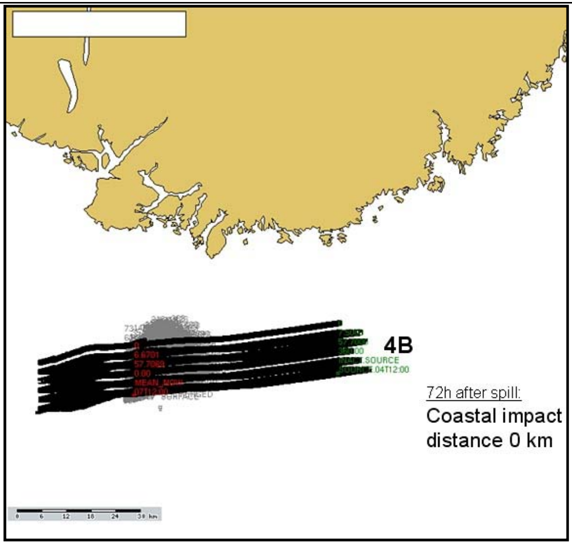
Table 8.2 Scenario at Egersund. Illustration of the oil drift 18 hours after the release of 1 000 m3 bunkers oil on one of today's routes and on the proposed route ,with key data concerning the scenario and simulation results.

<table>
<tr><th>Today's routes
Situation after 18 hours</th><th>Proposed route
Situation after 18 hours</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Scenario 3A and 3B are identical except from location:
• Location A: N58^{0}30', E005^{0}32' - a high density traffic spot based on AIS data
• Location B: N58^{0}21', E005^{0}12' - closest point to (A) given new routing, south bound
Key data concerning the scenario:
• Type of incident: Collision, ore carrier
• Time of year: Spring
• Release type: Sea surface release
• Oil type: Bunkers, IFO260 (intermediate fuel oil)
• Release volume: 1000 m^3 during 4 hours
• Weather: Wind 10 m/s from 200 deg, 0,15 km sea current along coastline towards north-west</td></tr>
<tr><td>Simulation results
• Time from release to shoreline impact:10 h
• Initial shoreline impact length: 20 km
• Oil volume reaching shoreline, first batch: 998 m^3</td><td>Simulation results
• Time from release to shoreline impact:70 h
• Initial shoreline impact length: 35 km
• Oil volume reaching shoreline: 780 m^3</td></tr>
</table>

Source: Norconsult: In TØI-report 1037/2009, Appendix 8

Table 8.3 gives the simulation results from the case scenario at Ryvingen. The effects of adopting the proposed route are more favourable at Ryvingen. Given our scenario there will be no shoreline impacts of oil released in the new proposed route, while for the same amount of oil released today 998 m^3 will reach the shoreline.

Table 8.3 Scenario at Ryvingen. Illustration of the oil drift 72 hours after the release of 20 000 m3 crude oil on one of today's routes and on the proposed route ,with key data concerning the scenario and simulation results.

Today`s routes *Situation after 72 hours*	**Proposed route** *Situation after 72 hours*
	

Scenario 4A and 4B are identical except from location:

- Location A: N57^{0}54', E007^{0}30' - a high density traffic spot based on AIS data
- Location B: N57^{0}42', E007^{0}30' - closest point to (A) given new routing, east bound

Key data concerning the scenario:

- Type of incident: Collision
- Time of year: Autumn
- Release type: Release from sea bed (A: -183m, B: -349 m)
- Oil type: Light crude oil (Draugen)
- Release volume: 20 000 m^3 during 24 hours
- Weather: Wind 15 m/s from 150 deg, 0,15 km sea current along coastline towards south-west

Simulation results	**Simulation results**
• Time from release to shoreline impact:12 h • Initial shoreline impact length:60 km • Oil volume reaching shoreline, first batch: 9 000 m^3	• Time from release to shoreline impact: No shoreline impact • Initial shoreline impact length: 0 km • Oil volume reaching shoreline, first batch: 0 m^3

Source: Norconsult: In TØI-report 1037/2009, Appendix 8

In general, the perhaps greatest benefit of adopting the proposed route is the increase in time for an oil spill release to reach the shoreline. This results in more natural degradation in the sea and the air, and allows the authorities more time to react. The time it takes for the oil to drift to the shoreline is increased from 10 to 70 hours for the Egersund scenario. For the Ryvingen scenario the oil is expected to drift past Norwegian shorelines.

8.3 Environmental consequences of oil spills

The marine environment and its inhabitants are threatened by many factors. Utilization, habitat destruction and climate changes are just some of them. An oil spill incident may harm populations or ecosystems in different ways and to different degrees according to the environmental pressure the area or population are already experiencing. The toxic components of oil, the polycyclic aromatic hydrocarbons may cause physical, physiological or behavioral damages to the flora and fauna affected. This may lead to lethal or sub lethal effects.

Fish and invertebrates are vulnerable to oil spills. Due to the nature of oil, where it is transported and spread on the surface before it hits the shore; the bottom living animals in the open sea are less vulnerable than pelagic living, but in the coastal area both pelagic and bottom living may be affected. They are mostly exposed to water soluble components as their main source of contact would be through respiration from water through their gills.

Seabirds are probably one of the most vulnerable animal groups to oil spills. Oil polluted birds are often the most prominent picture from a spill incident, but studies also conclude that oil spills have contributed to decreased populations of seabird species. This has not yet been shown for other animal groups. As for some mammals, the external pollution is the most acute. Oil in the feathers results in clogging and reduction of the water resistance, and it prevents the insulation ability of the feathers and reduces the ability for heat regulation.

Sea living mammals may be affected by oil spills in different ways. They should be able to swim out of an area, and whales have in experiments learned to avoid areas of oil spills after first encounter with the spill. However, common seals have shown the opposite behavior during the Exxon Valdez accident, rather seemed to be attracted by the spill.

8.4 Environmental impacts at Egersund and Ryvingen

To assess the environmental consequences for each case we have chosen to use the relative difference of impact areas as the main parameter. This is due to the fact that the actual oil spill concentration and distribution within the archipelago is highly dependent on a wide range parameters not part of today's model tools.

MOB (Miljø og beredskap ≈ Environmental Contingency) is the national regime for the prioritization of environmental resources during oil spills emergency response in Norwegian waters. The prioritizing is made up by a system of parameters e.g. oil pollution vulnerability, conservation value, the resource's natural occurrence as well as whether the environmental loss can be compensated economically or not. These parameters form the basis for the priority category, which range from A-D; with A being the highest level of priority. The prioritizing work has been conducted by the local environmental authority.

Our quantification is performed by summarizing the MOB areas of different categories within the scenario impact areas. The data used for these scenarios are based upon the data from *Kystinfo*, the public GIS tool of the Norwegian Coastal Administration.

Most of the MOB areas that may be affected by an oil spill at Egersund and Ryvingen are seabird habitats where birds breed and feed. Some also use these sites for resting on their way southwards in the autumn and others will spend the winter here. There is a wide range of different seabird species, some are diving for food while others are surface feeders. All these strategies may make the birds vulnerable for injuries and subjected to prey deficiency in case of an oil spill that covers big parts of their target area.

The area is also home to marine mammals. An incident happening in the spring that coincides with hatching and birth may cause severe injuries and increase the mortality for this offspring. Scenario A will affect only a limited amount of recreational areas while the B scenario will affect more areas of this category. There are registered observations of deep water corals (*Lophelia pertusa)* in the area affected by scenario B. This specie is red listed but live below 40 m depth, and will therefore not be directly exposed. For details about environmental impacts please see Appendix 8.

Summing up the environmental impacts for scenario Egersund, the total number of MOB areas affected with today's routes are 12 and with the proposed route 98. This is of course a considerable increase owing to the much larger potential impact area. Still, an increase in MOB areas does not necessarily imply increased environmental damages. This will be heavily influenced by the amount of spill actually reaching the shores, depending on oil spill response and natural degradation.

The larger impact area of an oil spill occurring farther away from the shore indicates that a higher number of sites may be exposed to the spill. However experience shows that the number of impact sites is not proportionate to the total impact area and may also be counter balanced by the lower concentration of oil (severity of impact) on each site. From past spills oil has been observed accumulating in patches.

The extended drifting distance may decrease the impact intensity and hence ease the effect for the local populations within a region. This means that e.g. neighboring bird populations may not be effected, directly or through polluted or shortage of prey, to the same degree and migration between them decrease the overall impact. The same may be the result for a local fish stock, a seal or otter population etc.

For the Ryvingen scenario the MOB for today's routes are 131 and for the proposed route the MOB was not applicable.

8.5 Clean-up costs

The oil spill response may reduce the volume of oil reaching the coast. The efficiency of open ocean oil spill response is highly dependent on prevailing weather and coastal currents. In Norway, there are 16 governmental oil spill response depots, and off-shore oil spill response equipment (booms and skimmers) are located on board Royal Norwegian Coastguard vessels patrolling the coastline. The depots are dependent on use of vessels of opportunity. In the vicinity of scenario Egersund, oil spill response depots are located in Stavanger. Closest depot to scenario Ryvingen is Kristiansand.

When assessing the consequence reducing effect of oil spill response, a generic approach was adopted based on experience from oil spill operations in Norway during the last 20 years was used. A range of assumption and parameters were used (see Appendix 8 for details).

For scenario Egersund oil recovered at sea is expected to be 45 m^3, and the oil reaching shore to be 953m^3 for today's routes. For the proposed route the oil recovered at sea is expected to be 748 m^3 and 250 m^3 is expected to reach the shores. Based on this the clean-up costs are calculated to be 190 million NOK for today's routes and 50 million NOK for the proposed route.

For scenario Ryvingen oil recovered at sea is expected to be 325 m^3, and the oil reaching shore to be 8675 m^3 for today's routes. For the proposed route the oil recovered at sea was not applicable and no oil reached the shores. Clean-up costs are calculated to be 347 million NOK for today's routes and 15 million NOK (saving and cleaning) for the proposed route. No oil reaches the shoreline and within 5-6 days in the prevailing wind conditions and temperatures, this oil is expected to naturally degrade (evaporation, dispersion).

8.6 Emergency towing

To assess the potential for emergency towing, preventing ship grounding (and spill), time from propulsion failure (at position A and B for each scenario cf. figure 8.1) until grounding has been calculated and compared with tug boat response times.

According to NCA (Kystverket 2006b) drifting speed for large vessels varies between 1.2 to almost 4 knots, depending on ship dimensions, wind and ocean current. For this comparative analysis, the shortest drifting distance and 2.5 knot (wind above 10 m/s) and 2.0 knot (wind below 10 m/s) drift speed was used to calculate maximum tug boat response times.

Actual tug boat availability per 2008 in the vicinity of the scenario areas was used for this analysis. Results show that tug boat response times would be too great to prevent grounding for the both scenarios with today's routes. For the proposed route tug boat response time would be sufficient to prevent grounding for both scenarios. For the details please see Appendix 8.

8.7 Conclusion scenario Egersund

The results of the accident scenario outside Egersund where 1000 tonnes of bunker oil was released are summed up in table 8.4.

The probability of a spill accident decreases with the proposed measure. Also the probability of a oil tanker collisions is smaller on the proposed new route than on today's routes, and the portion of the fuel or bunker oil of 1000 m3 reaching the shoreline is dramatically reduced. The number of vulnerable areas affected given the above spill are increased. A main improvement is the availability of tugs in the proposed new route.

Table 8.4 Environmental consequences of implementing the proposed new route at Egersund.

	Today's routes	Proposed route
Spill accidents per year 2008/2025	0,250/0.451	0,210/0,311
Oil tanker collisions (causing oil spills) per year 2008/2025	0,0241/0,0372	0,0167/0,0300
Proportion of the released oil that reaches the shore	95%	25%
Recovery costs (saving and cleaning) mill. NOK	190	50
Time from oil release to shoreline impact	10 hours	70 hours
Tug in time	No	Yes
Number of MOB (vulnerable) areas affected	12	98

Source: Norconsult: In TØI-report 1037/2009, Appendix 8

8.8 Conclusion scenario Ryvingen

The results of the accident scenario outside Ryvingen where 20 000 tons crude oil oil was released are summed up in table 8.5. The probability of spill accidents decreased for the proposed route. The oil does not reach the shoreline with the proposed route. Again a main improvement is the availability of tugs in the proposed new route.

Table 8.5 Environmental consequences of implementing the proposed new route at Ryvingen

	Today's routes	Proposed route
Spill accident per year 2008/2025	0,096/0,119	0,070/0,082
Oil tanker collisions (causing oil spills) per year 2008/2025	0,0131/0,0174	0,0072/0,0099
Proportion of the released oil that reaches the shore	43%	0%
Recovery costs (Saving and cleaning) mill. NOK	347	15
Time from oil release to shoreline impact	12 hours	No impact
Tug in time	No	Yes
Number of MOB (vulnerable) areas affected	131	n/a

Source: Norconsult: In TØI-report 1037/2009, Appendix 8

9 Discussion and conclusion

9.1 Reduced oil spills

Our findings show that implementing a routeing measure for tankers and vessels above 5000 GT off the Norwegian coast will significantly reduce the probability of accidents, including those causing oil spills. The proposed routeing measure will reduce oil and bunkers spills for all vessels by an estimated 27 per cent (550 tonnes) as of 2008 and by 65 per cent (2560 tonnes) as of 2025.

Our results also indicate that very large oil spills will occur less often and farther away from the coast, thus allowing authorities more time to react. More efficient natural degradation of oil will also occur through evaporation and natural dispersion causing (in most cases) significantly reduced environmental impact. This general conclusion is also supported by the two case studies, where two different oil spill scenarios were analyzed.

The highest benefit of routeing vessels farther away from the coast will be related to crude oil spills from tanker accidents. This is exactly the type of risk at which the proposed routeing measure is addressed, hence it seems to be a quite effective countermeasure. The favourable effect of routeing holds true for various traffic density levels. Given the traffic density forecast for 2025 the proposed measure gives stronger positive effects than with today's traffic.

There is of course a strong correlation between oil spills and spilling accidents. However, not all spilling accidents result in huge oil spills. Even if the calculated changes in accident frequencies did not reach statistical significance, the significant change in oil spill volumes indicates that large spilling accident involving oil tankers will also be substantially reduced by adopting the proposed routeing measures.

There are few adverse environmental effects of adopting the proposed routeing measure. The most important factor is a potentially larger coastline impact area for oil spills. For crude oil, this negative effect is counterbalanced by increased evaporation and natural degradation of oil resulting from increased distance to the cost. Fuel oil spills from locations along the proposed traffic lane may hit a larger impact area. It is, however, possible that this risk will be mitigated by increased time for oil spill response by the authorities, given an accident.

9.2 Increased shipping costs

The main argument against the proposed routeing measure is on the cost side. The proposed new route being longer than most routes followed today, it will lead to an increase in total ship miles travelled between Utsira and the Oslo fjord. However, for the transit traffic from the North Sea to the Baltic Sea, the proposed route will only give minor increases in shipping distances.

The overall increase in traffic volume translates into a corresponding increase in shipping costs. Our study has not, unfortunately, had access to sufficiently reliable unit cost data for the accurate calculation of shipping cost increases. In addition we do not know how many of the domestic ships that will follow the proposed route. In our accident simulation model we have assumed that all ships above 5000 GT will move to the proposed route. Ships travelling between Norwegian ports will however not be obliged to follow the proposed route if this route is adopted. Some domestic tankers will, due to the companies' risk management policies, travel the proposed route even though they are not obliged to do so and in spite of the resulting cost increase.

For the tanker traffic from the Barents Sea along the Norwegian coast to the Baltic Sea and for the traffic to and from the oil installations in the Norwegian Sea the proposed routeing measure will only generate a minor cost increase. For these ships the proposed route is only marginally longer than the route they normally travel today and one major benefit of the proposed route is the segregation scheme adopted.

9.3 Conclusion

In sum it seems clear that the proposed routeing measure reduces both the probability of accidents and the consequences of possible accidents. Thus, adopting the proposed routeing measures will give a significant risk reduction.

In our simulations and calculations, all traffic above 5000 GT has been moved to the proposed route. As domestic traffic will not be obliged to follow the new route, it is likely that the traffic density on the proposed route will be lower than assumed in our simulations. Accordingly the risk of collisions and oil pollution may be reduced even more than our estimates indicate.

Due to lack of sufficient details on costs and benefits, it has not been possible to determine whether the benefits of the proposed measure outweigh the cost. For the tanker traffic along the coast it seems however clear that benefits outweigh the costs by far. For the total ship traffic chances are, however, that in an average year the savings in accident and oil spill costs do not outweigh the increase in shipping costs. This possible negative benefit-cost differential could, however, be regarded as an insurance premium against the consequence of very large oil spills, of which the figures on expected (average) annual cost savings would not be representative.

The expected reduction in total oil spill volumes is predominantly a result of an expected decline in tanker oil spills. The proposed measure is in particular addressed towards managing these environmental risks mitigating the effects of the expected tanker traffic increase along the Norwegian coast. It seems, accordingly, reasonable to conclude that the proposed new route is a quite appropriate counter measure.

References

Akhtar, J., & Jean-Hansen V. (2009). Effects of proposed ship routeing off the Norwegian coast. Part 1 Røst – Utsira. *TØI report 1036/2009.*

Bambulyak, A., & Frantzen, B. (2009). Oil transport from the Russian part of the Barents Region.

Eriksen, T., Høye, G., Narheim, B., & Meland, B. J. (2006). Maritime traffic monotoring using a space-based AIS.

Hovi, I., & Madslien, A. (2008). Revised forecast for Norwegian freigth transport 2006-2040. TØI report 1001/2008.

Kystverket (2006a). Stamnettsutredning - Kystverket Troms og Finnmark

Kystverket (2006b). Nasjonal slepeberedskap (National emergency tug preparedness).

Loeng, H., & Drinkwater, K. (2007). An overview of the ecosystems of the Barents and Norwegian Seas and their response to climate variability. Deep-Sea research, 54.

Norconsult (2006). Forventet skipsutvikling de neste 30 årene. Trondheim.

Safetec (2007). RKU Nordsjøen. Beskrivelse av skipstrafikken i Nordsjøen.

Sjøfartsdirektoratet (2009). 103 grunnstøtninger i 2008. Faktaark.

Appendices

Appendix 1 Traffic on today's routes and on the proposed route

Table 1 shows the transfer of traffic from the today's routes (see figure 1-2) to the proposed route (figure 3). The traffic in the crossing lanes are kept unchanged.

Table 1Waypoints

Proposed route (one way)	*Today's routes (two ways)*
[Waypoints]	
3-4 and reverse	21-22and reverse
4-5 and reverse	22-23 and reverse
5-6 and reverse	23-24 and reverse
6-7 and reverse	26-27 27-28 and reverse
7-8 and reverse	28-29 and reverse
31 -30 and 21-20 (south)	Estimation from other traffic data *
51-50 and 40-41	25-24 and reverse
Alt.lane (one way)	Today's lane (two ways)

** The amount of traffic south from Norway is approximately the traffic of lane 40-42, the traffic in lane 22-23 subtracted.*

Today’s routes

FID	Shape *	Id	Name	ET ID	ET X	ET Y	ET ORDER	ET IDR	ET IDP	X DMS	Y DMS
0	Point	0		0	9,2604	57,74202	0	0_0	0	9°15'37"	57°44'31"
1	Point	0		0	7,0321	57,7211	0,1727	0_0	0	7°01'55"	57°43'16"
2	Point	0		0	6,3891	57,85473	0,2261	0_0	0	6°23'21"	57°51'17"
3	Point	0		0	5,1886	58,38184	0,3456	0_0	0	5°11'19"	58°22'55"
4	Point	0		0	4,6105	58,66212	0,4053	0_0	0	4°36'38"	58°39'44"
5	Point	0		0	4,267	59,33006	0,5054	0_0	0	4°16'01"	59°19'48"
6	Point	0		0	4,7427	59,33318	0,5405	0_0	0	4°44'34"	59°19'59"
7	Point	0		0	5,2517	58,81961	0,624	0_0	0	5°15'06"	58°49'11"
8	Point	0		0	5,6221	58,5239	0,6751	0_0	0	5°37'19"	58°31'26"
9	Point	0		0	6,6037	58,04514	0,7772	0_0	0	6°36'13"	58°02'43"
10	Point	0		0	7,1215	57,94608	0,8195	0_0	0	7°07'17"	57°56'46"
11	Point	0		0	9,1988	57,87576	0,98	0_0	0	9°11'56"	57°52'33"
12	Point	0		1	8,2828	57,98892	0	1_0	1	8°16'58"	57°59'20"
13	Point	0		1	7,8072	57,9121	0,0813	1_0	1	7°48'26"	57°54'44"
14	Point	0		1	7,5001	57,92491	0,1317	1_0	1	7°30'00"	57°55'30"
15	Point	0		1	8,1864	58,06876	0,2522	1_0	1	8°11'11"	58°04'08"
16	Point	0		1	8,8667	58,39266	0,4009	1_0	1	8°52'00"	58°23'34"
17	Point	0		1	9,6674	58,85427	0,5925	1_0	1	9°40'03"	58°51'15"
18	Point	0		1	9,9263	58,69795	0,656	1_0	1	9°55'35"	58°41'53"
19	Point	0		1	9,0413	58,31672	0,8406	1_0	1	9°02'29"	58°19'00"
20	Point	0		0	4,5049	59,33184	0		0	4°30'18"	59°19'55"
21	Point	0		0	4,9304	58,74127	0		0	4°55'49"	58°44'29"
22	Point	0		0	5,4049	58,45305	0		0	5°24'18"	58°27'11"
23	Point	0		0	6,4961	57,94999	0		0	6°29'46"	57°57'00"
24	Point	0		0	7,0766	57,8336	0		0	7°04'36"	57°50'01"
25	Point	0		0	9,2296	57,80889	0		0	9°13'47"	57°48'32"
26	Point	0		0	7,6537	57,9186	0		0	7°39'13"	57°55'07"
27	Point	0		0	8,2347	58,02885	0		0	8°14'05"	58°01'44"
28	Point	0		0	8,9541	58,35472	0		0	8°57'15"	58°21'17"
29	Point	0		0	9,7971	58,77617	0		0	9°47'50"	58°46'34"

FID	Shape *	Id	ET From	ET From 1	ET To	ET Length Nauthmiles	ET Length meters	ET Angle degree	Width meters	Width nm
0	Polyline	0	0	0	11	8,286	15357,1	341	7678,5	4,143
1	Polyline	0	1	0	10	13,825	25622,3	9	12811,1	6,913
2	Polyline	0	2	0	9	13,342	24725,7	28	12362,8	6,671
3	Polyline	0	3	0	8	16,103	29842,8	56	14921,4	8,051
4	Polyline	0	4	0	7	22,152	41054,4	63	20527,2	11,076
5	Polyline	0	5	0	6	14,606	27069,5	88	13534,7	7,303
6	Polyline	0	12	0	15	5,701	10566,1	323	5283	2,851
7	Polyline	0	13	0	14	9,854	18262,4	271	9131,2	4,927
8	Polyline	0	16	0	19	7,167	13282,3	125	6641,1	3,583
9	Polyline	0	17	0	18	12,411	23000,7	133	11500,3	6,205

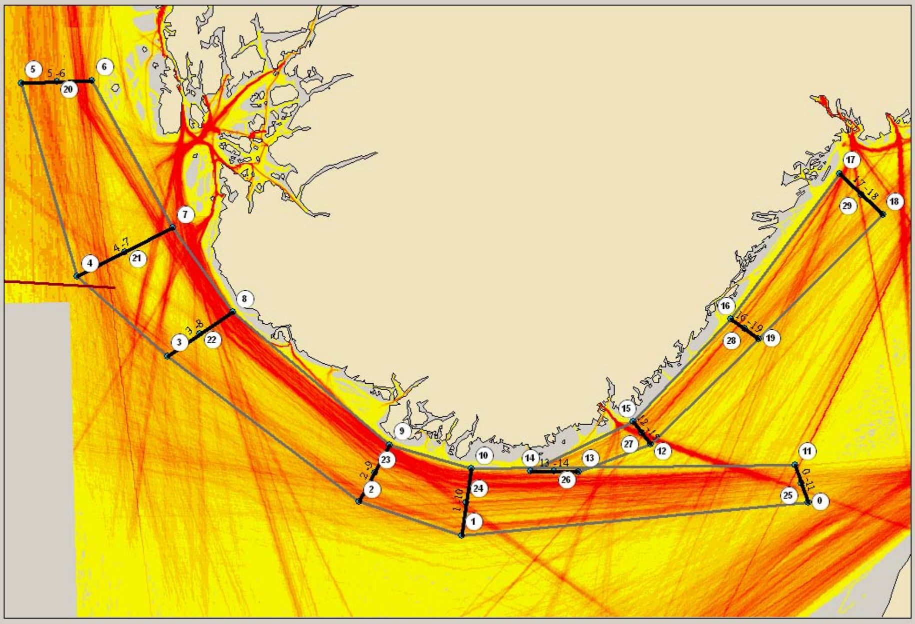


Figure 1 Today’s routes

FID	Shape *	Id	Name	ET ID	ET X	ET Y	ET ORDER	ET IDR	ET IDP	X DMS	Y DMS
0	Point	0		0	9,66179	65,87203	0	0_0	0	9°39'42"	65°52'19"
1	Point	0		0	5,50276	62,83993	0,0734	0_0	0	5°30'10"	62°50'24"
2	Point	0		0	7,88506	64,34075	0,1116	0_0	0	7°53'06"	64°20'27"
3	Point	0		0	10,55887	66,11079	0,1552	0_0	0	10°33'32"	66°06'39"
4	Point	0		0	12,07688	67,14896	0,1802	0_0	0	12°04'37"	67°08'56"
5	Point	0		0	14,00742	67,98122	0,2034	0_0	0	14°00'27"	67°58'52"
6	Point	0		0	14,40037	67,77582	0,2087	0_0	0	14°24'01"	67°46'33"
7	Point	0		0	12,74569	67,02609	0,2292	0_0	0	12°44'44"	67°01'34"
8	Point	0		0	11,13867	65,97946	0,2548	0_0	0	11°08'19"	65°58'46"
9	Point	0		0	8,21901	64,2655	0,2987	0_0	0	8°13'08"	64°15'56"
10	Point	0		0	6,2352	63,03255	0,3302	0_0	0	6°14'07"	63°01'57"
11	Point	0		0	7,17871	63,2766	0,3404	0_0	0	7°10'43"	63°16'36"
12	Point	0		0	7,34603	63,17512	0,3431	0_0	0	7°20'46"	63°10'30"
13	Point	0		0	6,05688	62,75842	0,358	0_0	0	6°03'25"	62°45'30"
14	Point	0		0	5,16314	62,31855	0,3706	0_0	0	5°09'47"	62°19'07"
15	Point	0		0	4,48515	61,66037	0,3858	0_0	0	4°29'07"	61°39'37"
16	Point	0		0	4,85566	58,62063	0,4491	0_0	0	4°51'20"	58°37'14"
17	Point	0		0	3,89033	58,66092	0,4596	0_0	0	3°53'25"	58°39'39"
18	Point	0		0	3,81882	61,69613	0,5226	0_0	0	3°49'08"	61°41'46"
19	Point	0		0	5,94697	65,20489	0,5982	0_0	0	5°56'49"	65°12'18"
20	Point	0		0	9,7628	68,1862	0,6678	0_0	0	9°45'46"	68°11'10"
21	Point	0		0	10,2954	68,12339	0,6721	0_0	0	10°17'43"	68°07'24"
22	Point	0		0	6,3567	65,09517	0,743	0_0	0	6°21'24"	65°05'43"
23	Point	0		0	4,51969	62,3306	0,8029	0_0	0	4°31'11"	62°19'50"
24	Point	0		0	8,93842	65,94222	0,8881	0_0	0	8°56'18"	65°56'32"
25	Point	0		0	12,10684	68,18295	0,9414	0_0	0	12°06'25"	68°10'59"
26	Point	0		0	12,82812	68,0697	0,9474	0_0	0	12°49'41"	68°04'11"
27	Point	0		0	10,02947	68,155	0		0	10°01'46"	68°09'18"
28	Point	0		0	12,46839	68,12671	0		0	12°28'06"	68°07'36"
29	Point	0		0	14,20476	67,87862	0		0	14°12'17"	67°52'43"
30	Point	0		0	12,41215	67,08787	0		0	12°24'44"	67°05'16"
31	Point	0		0	10,84953	66,04539	0		0	10°50'58"	66°02'43"
32	Point	0		0	9,30062	65,90755	0		0	9°18'02"	65°54'27"
33	Point	0		0	6,15226	65,15017	0		0	6°09'08"	65°09'01"
34	Point	0		0	8,05227	64,30322	0		0	8°03'08"	64°18'12"
35	Point	0		0	7,26252	63,22588	0		0	7°15'45"	63°13'33"
36	Point	0		0	5,86778	62,93672	0		0	5°52'04"	62°56'12"
37	Point	0		0	5,78021	62,79945	0		0	5°46'49"	62°47'58"
38	Point	0		0	5,00701	62,58615	0		0	5°00'25"	62°35'10"
39	Point	0		0	4,84149	62,32495	0		0	4°50'29"	62°19'30"
40	Point	0		0	4,15218	61,67865	0		0	4°09'08"	61°40'43"
41	Point	0		0	4,1656	62,01383	0		0	4°09'56"	62°00'50"
42	Point	0		0	4,37329	58,64168	0		0	4°22'24"	58°38'30"

FID	Shape *	Id	ET From	ET To	ET Length nm	ET Length meter	ET Angle degree	Width meters	Width nm
0	Polyline	0	0	24	18,292	33900,3	278	16950,1	9,146
1	Polyline	0	1	10	23,17	42940,6	57	21470,3	11,585
2	Polyline	0	1	13	16,021	29691	105	14845,5	8,01
3	Polyline	0	1	23	40,992	75970,1	220	37985,1	20,496
4	Polyline	0	2	9	9,83	18216,8	113	9108,4	4,915
5	Polyline	0	3	8	16,251	30118,1	112	15059,1	8,126
6	Polyline	0	4	7	17,368	32188,4	107	16094,2	8,684
7	Polyline	0	5	6	15,275	28309,1	134	14154,6	7,638
8	Polyline	0	11	12	7,608	14099,3	140	7049,6	3,804
9	Polyline	0	14	23	18,008	33373,6	271	16686,8	9,004
10	Polyline	0	15	18	19,152	35493,5	275	17746,7	9,576
11	Polyline	0	16	17	30,336	56220,7	273	28110,4	15,168
12	Polyline	0	18	23	42,973	79641,2	26	39820,6	21,487
13	Polyline	0	19	22	12,292	22780,3	120	11390,1	6,146
14	Polyline	0	20	21	12,531	23222,7	101	11611,3	6,265
15	Polyline	0	25	26	17,59	32599,2	104	16299,6	8,795

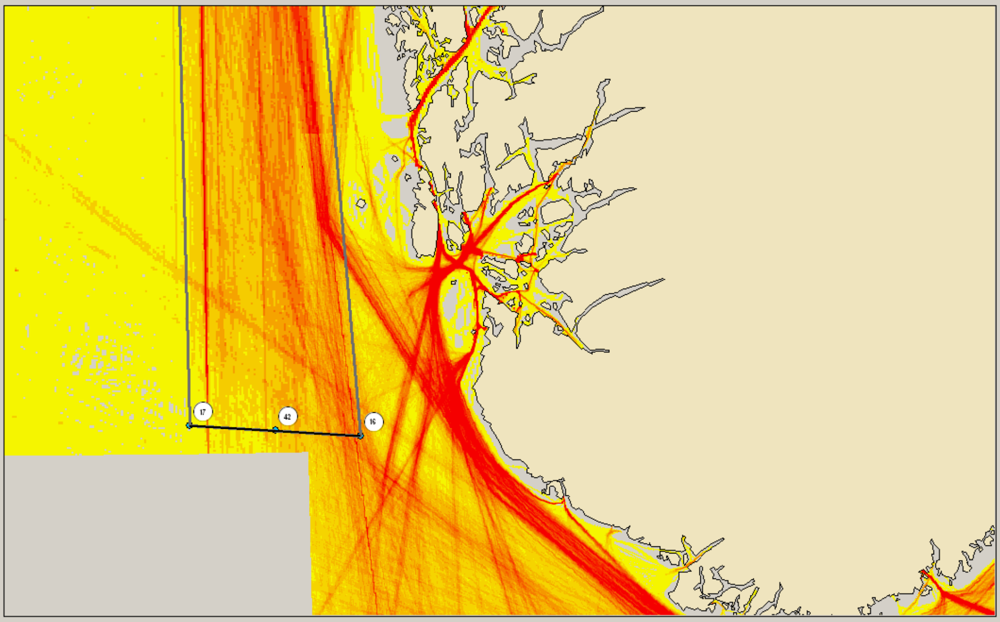
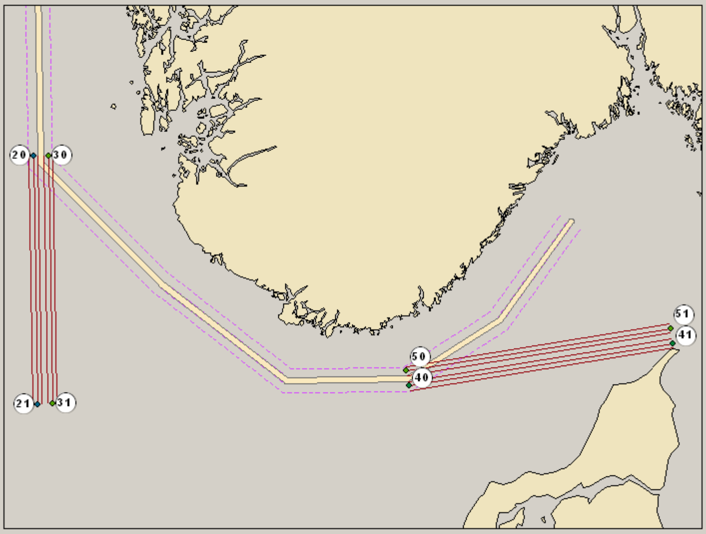


Figure 2 Today's routes Utsira

Proposed route

Merging traffic



FID	Shape *	Id	OBJECTID	Shape Leng	ET ID	ET X	ET Y	ET ORDER
0	Point	0	2	152255,067809	0	4°01'25"	59°02'25"	0
1	Point	0	2	152255,067809	0	4°01'36"	57°40'22"	1

FID	Shape *	Id	OBJECTID	Shape Leng	ET ID	ET X	ET Y	ET ORDER
0	Point	0	3	152255,067809	0	4°11'05"	59°02'25"	0
1	Point	0	3	152255,067809	0	4°10'54"	57°40'22"	1

FID	Shape *	Id	OBJECTID	Shape Leng	ET ID	ET X	ET Y	ET ORDER
0	Point	0	4	164141,974642	0	7°51'36"	57°41'04"	0
1	Point	0	4	164141,974642	0	10°36'20"	57°47'06"	1

FID	Shape *	Id	OBJECTID	Shape Leng	ET ID	ET X	ET Y	ET ORDER
0	Point	0	5	164141,974642	0	7°50'47"	57°46'02"	0
1	Point	0	5	164141,974642	0	10°35'54"	57°52'04"	1

Numbering (example); Number 21 means objectid 2 and FID 1

3	Point	0	1432073,66609	2	4°01'25"	58°59'11"	0,7009	2
4	Point	0	1432073,66609	2	5°17'14"	58°17'41"	0,7752	2
5	Point	0	1432073,66609	2	6°34'06"	57°42'57"	0,8447	2
6	Point	0	1432073,66609	2	7°52'21"	57°41'00"	0,899	2
7	Point	0	1432073,66609	2	8°54'02"	57°58'34"	0,9474	2
8	Point	0	1432073,66609	2	9°44'39"	58°29'02"	1	2

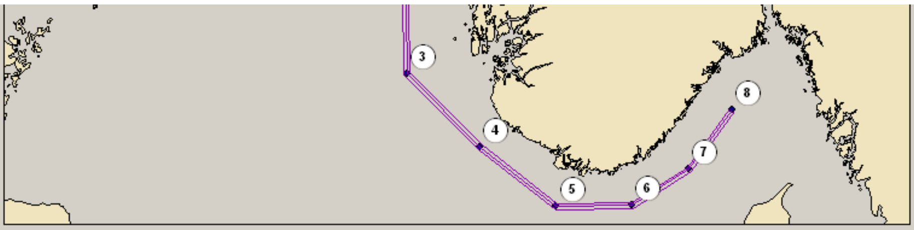


Figure 3 Proposed route Utsira – Oslo fjord

Appendix 2 Vessel velocity and length

Vessel velocity

Figure 2.1 gives a plot of velocity of vessels of 100 meter and above for the traffic for the year 2008. Different velocities are indicated by different colours in the plots. The colour keys can be read in the appurtenant colour boxes.

Most of the coast is coloured blue and green indicating that most vessels of 100 metres and above travel with speeds around 12 - 14 knots. The number of vessels in the area can also be read on the appurtenant colour boxes, indicated by the numbers given. The average speed for the entire areas is calculated to be 13.0 knots for vessels above 100 meters (assuming that the last speed category (coloured red) is 17 knots in average).

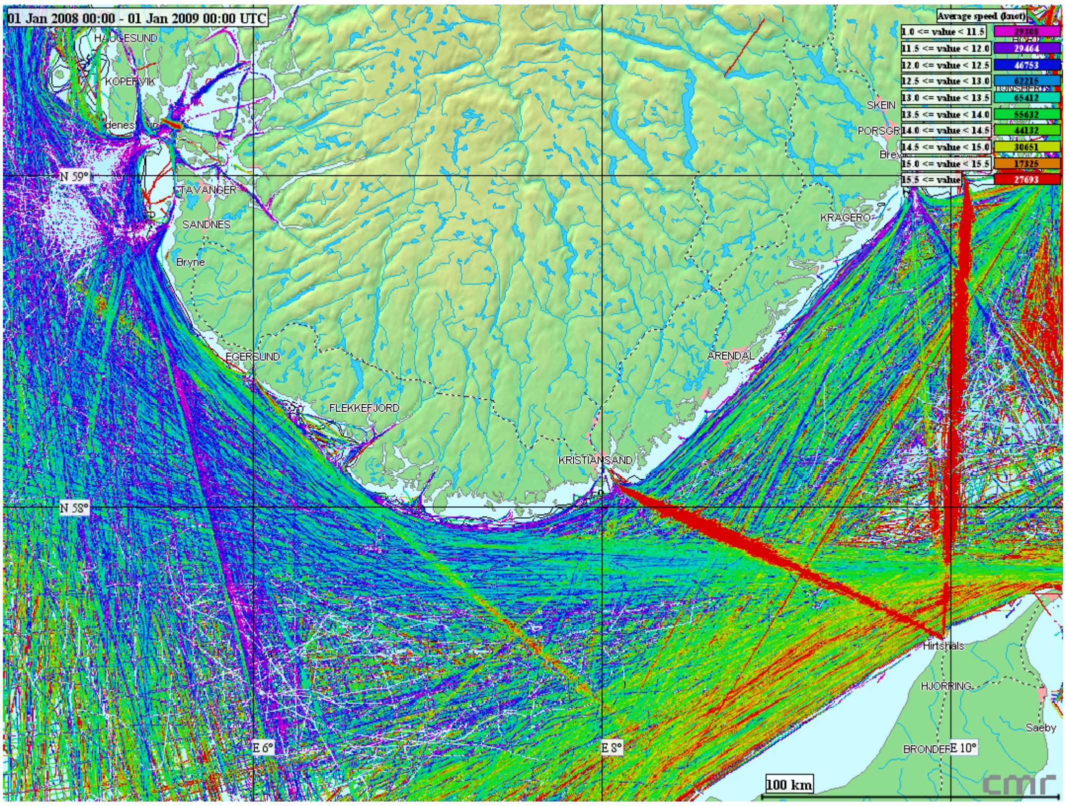


Figure 2.1 Vessel velocities Utsira – Oslo fjord

Vessel lengths

Figure 2.2 gives a plot of vessel lengths for the year 2008. Different vessel lengths are indicated by different colours in the plots. The colour keys can be read in the appurtenant colour boxes.

Vessel lengths differ systematically by distance to the shoreline. Traffic close to the shorelines is dominated by smaller ships (coloured violet and purple) whereas the larger ships (coloured red) typically travel farther off the coast and between ports in Norway and Denmark. The average length of vessels above 100 meters is calculated to be 153 meters (assuming the red category to have an average length of 250 meters).

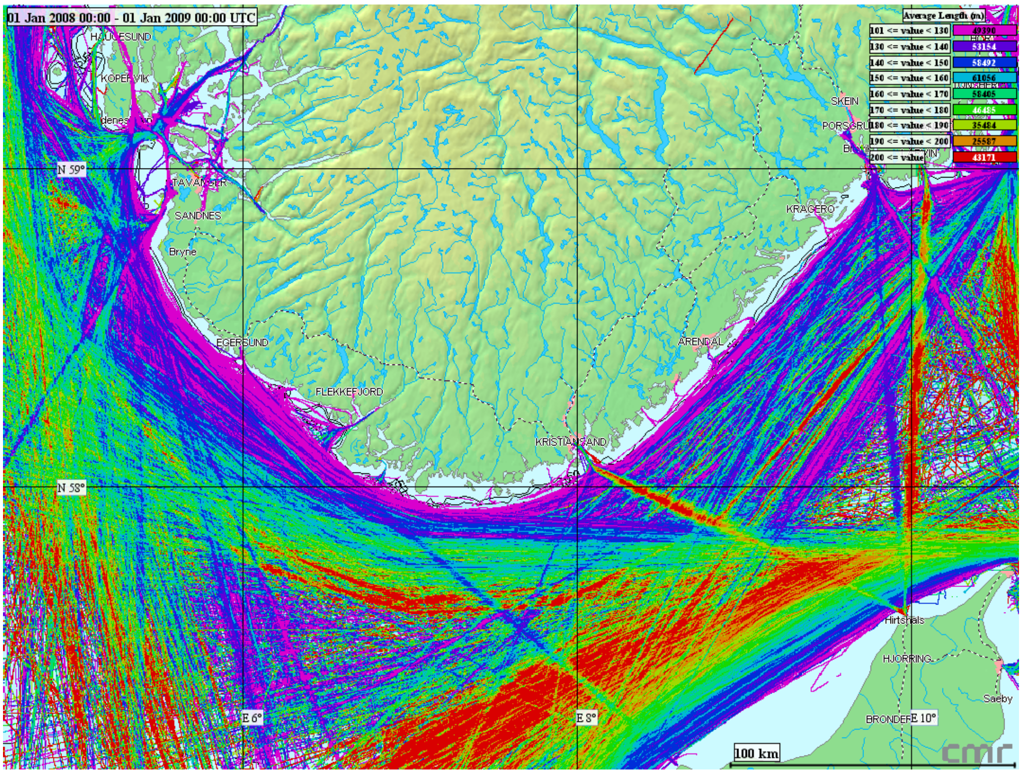


Figure 2.2 Vessel lengths Utsira – Oslo fjord

Appendix 3 Obstacles on or near the routes

Name	NS_decimal degrees	EW_decimal degrees
DUNKERQUE	2.461941	51.044438
ZEEBRUGGE	3.177500	51.340277
ZEEPIPE TERMINAL	3.177777	51.340277
EMDEN	7.218886	53.376941
EASINGTON	0.155555	53.641666
H-7	6.035874	54.509336
TEESSIDE	-1.295555	54.625833
36/22	0.203405	55.291105
B-11	4.551647	55.462313
37/4	1.612222	55.900166
HOD	3.460061	56.176533
VALHALL FLANKE SØR	3.437394	56.227711
VALHALL WIP	3.396338	56.276516
VALHALL WP	3.396377	56.276569
VALHALL PCP	3.396638	56.277555
VALHALL DP	3.395330	56.278163
VALHALL Q	3.394277	56.278833
VALHALL FLANKE NORD	3.352641	56.324361
EMBLA	3.248263	56.333230
ELDFISK FTP-FL	3.267261	56.373758
ELDFISK FTP-BS	3.266530	56.374655
ELDFISK E	3.265205	56.375086
ELDFISK FTP	3.265933	56.375719
ELDFISK A	3.265802	56.376880
ELDFISK B-FL	3.219447	56.418238
ELDFISK B	3.218394	56.419330

EDDA FL	3.105577	56.463775
EDDA	3.104463	56.464838
EKOFISK A	3.222858	56.521013
EKOFISK SØR FL	3.218622	56.543280
EKOFISK W	3.217933	56.544197
EKOFISK BS1	3.217277	56.545083
EKOFISK M	3.223044	56.545377
EKOFISK M-BS	3.223044	56.545377
EKOFISK FTP	3.216738	56.546180
EKOFISK Q	3.216030	56.546980
EKOFISK J	3.221283	56.547199
EKOFISK H	3.213133	56.547211
EKOFISK X	3.218944	56.547638
EKOFISK X-BS	3.216569	56.547652
EKOFISK C	3.215516	56.547841
EKOFISK BS3	3.214516	56.548352
EKOFISK P	3.213652	56.548691
EKOFISK G	3.209986	56.549197
EKOFISK T	3.212580	56.549541
EKOFISK T WALL	3.212580	56.549541
EKOFISK R	3.211719	56.550658
EKOFISK S-BS	3.212272	56.551494
EKOFISK SBM-1	3.212283	56.551694
EKOFISK SBM-2	3.212305	56.551708
EKOFISK BS4	3.210813	56.551713
EKOFISK S	3.213816	56.551897
EKOFISK NORD FL	3.210186	56.552613
VEST EKOFISK	3.085599	56.563208
EKOFISK B	3.203688	56.565352
EKOFISK K	3.206105	56.565802
ALBUSKJELL F-FL	3.055161	56.618600
ALBUSKJELL F-BS	3.054580	56.619419

ALBUSKJELL F	3.053947	56.620536
TOR FL	3.327616	56.640936
ALBUSKJELL A-FL	2.941222	56.641019
ALBUSKJELL A-BS	2.940638	56.641819
TOR	3.326958	56.642072
ALBUSKJELL A	2.940008	56.642886
GYDA	3.085197	56.904924
TAMBAR	2.958780	56.982755
COD FL	2.435422	57.068480
COD	2.434722	57.069552
ULA QP	2.845983	57.111080
ULA DP	2.847330	57.111430
ULA PP	2.848569	57.111755
ST. FERGUS	-1.849999	57.553330
YME B	4.356055	57.754249
YME MOPUStor	4.535436	57.816088
YME-STL	4.550052	57.834299
PETROJARL VARG	1.890458	58.077880
VARG A	1.890469	58.077916
DRAUPNER E	2.466666	58.188694
DRAUPNER S	2.472666	58.188777
SLEIPNER A	1.908613	58.367313
SLEIPNER R	1.910530	58.368563
SLEIPNER T	1.906480	58.368605
SLEIPNER FL	1.912175	58.369402
SLEIPNER B	1.717897	58.417902
NAVION SAGA	1.887500	58.441416
BRAE A	1.281949	58.692483
PETROJARL 1	1.668136	58.713305
GRANE	2.487388	59.165238
BALDER FPU	2.359683	59.191213
RINGHORNE	2.449858	59.266058

KÅRSTØ	5.521358	59.273361
NATURKRAFT GASSKRAFTVERK KÅRSTØ	5.521358	59.273361
BYGNES	5.304763	59.299163
SLAGENTANGEN	10.530986	59.318455
KALSTØ	5.195147	59.333397
JOTUN B	2.366908	59.451019
JOTUN A	2.386358	59.455255
ALVHEIM FPSO	1.998449	59.567516
HEIMDAL	2.228805	59.574161
HEIMDAL HRP	2.228305	59.575299
FRØY	2.557777	59.734166

APPENDIX 4

DESCRIPTION OF THE MARCS MODEL

APPENDIX 4 – DESCRIPTION OF THE MARCS MODEL

Contents

I. DESCRIPTION OF THE MARCS MODEL

I.1 BACKGROUND

Transportation by sea using conventional shipping operations results in both economic benefits and associated ship accident risks, which can result in safety and environmental impacts. Analysis of historical ship accident data indicates that almost all open-water shipping losses (excepting causes such as war or piracy) can be categorised into the following generic accident types:

- Ship-ship collision;
- Powered grounding (groundings which occur when the ship has the ability to navigate safely yet goes aground, such as the *Exxon Valdez*);
- Drift grounding (groundings which occur when the ship is unable to navigate safely due to mechanical failure, such as the *Braer*);
- Structural failure/ foundering whilst underway;
- Fire/ explosion whilst underway;
- Powered ship collision with fixed marine structures such as oil platforms or wind turbines (similar definition to powered grounding);
- Drifting ship collision with fixed marine structures such as oil platforms or wind turbines (similar definition to drift grounding).

These generic accident types effectively represent the results of a high level marine transportation hazard identification (HAZID) exercise and are applicable for most marine transportation systems. However, each marine risk analysis should consider if additional locally specific accident modes apply. For example, in Prince William Sound, Alaska laden oil tankers are tethered to a tug for part of the transit to mitigate grounding accidents. However, the presence of the tug also introduces an extra accident mode (tanker grounds because tug actions are inappropriate). The presence or absence of such additional geographically specific accident modes should be verified on a project specific basis.

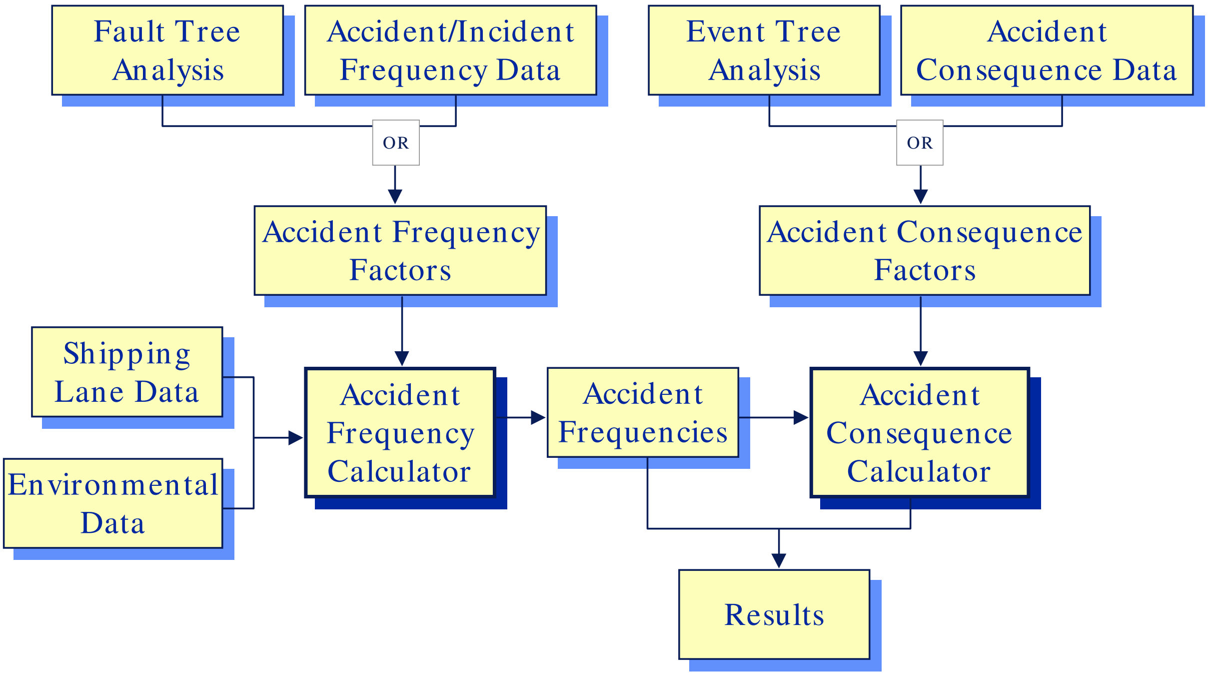
Marine transport risk analysis can be performed by assessing the frequency of the above accident types, followed by an assessment of the accident consequences, typically in terms of cargo spill, lives lost or in financial terms. DNV has developed the MARCS (Marine Accident Risk Calculation System) model to perform such marine transport risk analyses in a structured manner. The risk analysis results can then be assessed to determine if the estimated risks are acceptable or if risk mitigation is justified or required (risk assessment).

I.2 INTRODUCTION TO MARCS

I.2.1 Overview

The Marine Accident Risk Calculation System (MARCS) was developed by DNV to support our marine risk management consultancy business. The MARCS model provides a general framework for the performance of marine risk calculations. A block diagram of the model is shown in Figure I.1.

Figure I.1 Block Diagram of MARCS



The MARCS model classifies data into 4 main types:

- Shipping lane data describes the movements of different marine traffic types within the study area;
- Environment data describes the conditions within the calculation area, including the location of geographical features (land, offshore structures etc) and meteorological data (visibility, windrose, currents and seastate);
- Internal operational data describes operational procedures and equipment installed onboard ship – such data can affect both accident frequency and accident consequence factors;
- External operational data describes factors external to the ship that can affect ship safety, such as VTMS (Vessel Traffic Management Systems), TSS (Traffic Separation Schemes), and the location and performance of emergency tugs – such data can affect both accident frequency and accident consequence factors.

As indicated in Figure I.1, accident frequency and consequence factors can be derived in two ways. If a coarse assessment of accident risk is required, the factors may be taken from worldwide historical accident data. Alternatively, if a more detailed study is required, these factors may be derived from generic fault trees or event trees which have been modified to take account of specific local factors.

I.2.2 Critical Situations

MARCS calculates the accident risk in stages. It first calculates the location dependent frequency of critical situations (the number of situations which could result in an accident – "potential accidents" – at a location per year; a location is defined as a small part of the study area, typically about 1 nautical mile square, but depending on the chosen calculation resolution). The definition of a critical situation varies with the accident mode, see Section I.4. MARCS then assesses the location dependent frequency of serious accidents for each accident mode via "probability of an accident given a critical situation" parameters. A "serious accident" is defined by Lloyds as any accident where repairs must be made before the ship can continue to trade. Finally, the location dependent accident consequence, and hence risk, is assessed.

Analysis of these results for a specified area or trade enables the derivation of conclusions and recommendations on topics such as risk acceptability, risk reduction measures and cost-benefit analysis of alternative options.

I.2.3 Fault Tree Analysis

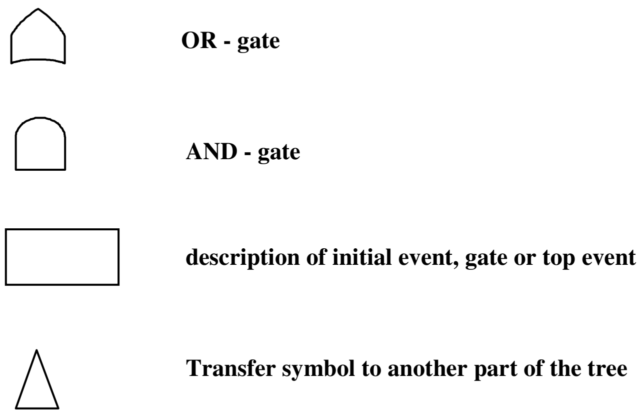
Fault tree analysis (see, for example, Henley E.J. and Kumamoto H., 1981 or Cooke R.M., 1995) can be described as an analytical technique, whereby an undesired state of a system is specified, and the system is then analysed in the context of its environment and operation to find all credible ways in which the undesired event can occur. This undesired state is referred to as the top event of the fault tree. It expresses the frequency or probability for the occurrence of this event or incident.

The basic events of a fault tree are those events that make up the bottom line of the fault tree structure. To perform calculations of the top frequency or probability of a fault tree, these basic events needs to be quantified.

The fault tree structure is built up by basic events, and logical combinations of these events which are expressed by AND and OR gates. The output of these gates are new events, which again may be combined with other events/basic events in new gates. The logic finally results in the top event of the fault tree. For example, fire occurs if combustible material AND air/oxygen AND an ignition source is present.

The different symbols in the fault tree are defined in Figure I.2.

Figure I.2 Fault tree symbols

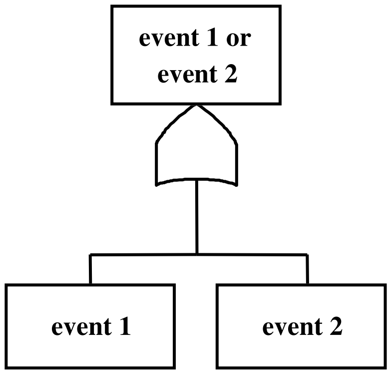


The OR gate, see Figure I.3, expresses the probability of occurrence of event 1 or event 2, and is calculated as the sum minus the intersection of the two events;

$$P(\text{event 1 OR event 2}) = P1 + P2 - P1*P2$$

Usually the intersection probability can be neglected, as it will be a very small number (if P1 = P2 = 10^{-2}, then P1*P2 = 10^{-4}).

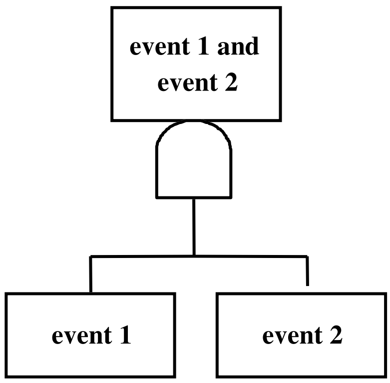
Figure I.3: OR - gate



The AND gate, see Figure I.4, expresses the probability that event 1 and event 2 occur simultaneously, and is calculated as the product of the two events;

P(event 1 AND event 2)= P1*P2

Figure I.4: AND - gate



It should be emphasised that the quality of the results produced by fault tree analysis is dependent on how realistically and comprehensively the fault tree model reflects the causes leading to the top event. Of course, it is never possible to fully represent reality, and therefore the models will always only represent a simplified picture of the situation of interest. The top event frequencies will generally be indicative, and hence relative trends are more secure than the absolute values.

Fault tree models have been constructed to assess a number of parameters within MARCS, including collision per encounter probabilities (collision model) and failure to avoid a powered grounding given a critical situation probabilities (powered grounding model) (SAFECO I; SAFECO II).

I.3 DATA USED BY MARCS

I.3.1 Traffic Image Data

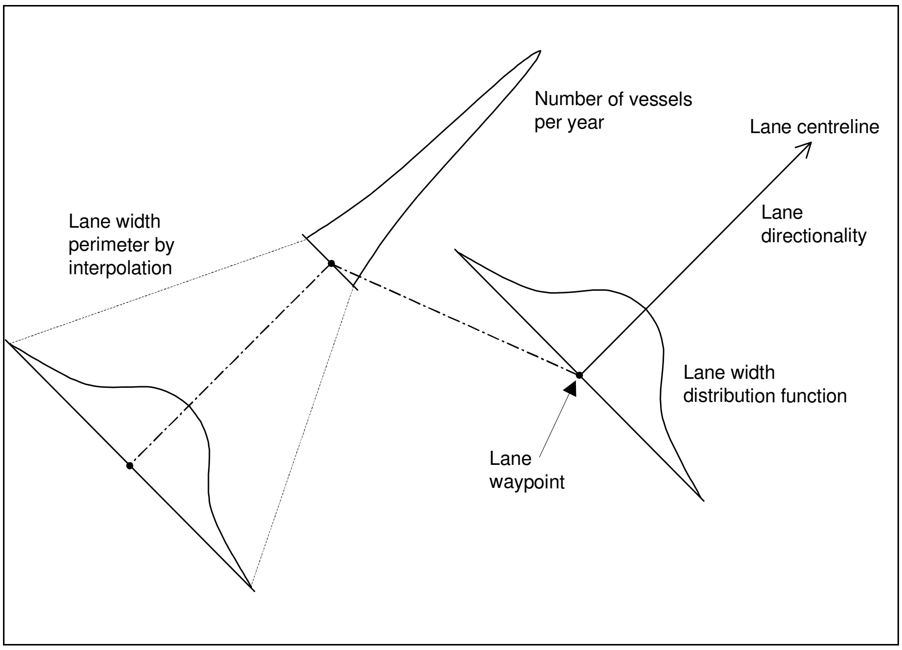
The marine traffic image data used by MARCS is a representation of the actual flows of traffic within the calculation area. Marine traffic data is represented using lane data structures. Different traffic types are divided into separate marine databases in order to facilitate data verification and the computation of different types of risk (for example, crude oil spill risk versus human safety).

A typical traffic lane is shown in Figure I.5. The following data items are defined for all lanes:

1. The lane number (a unique identifier used as a label for the lane);
2. The lane width distribution function (Gaussian or truncated Gaussian);
3. The lane directionality (one-way or two-way);
4. The annual frequency of ship movements along the lane;
5. A list of waypoints, and an associated lane width parameter at each waypoint;
6. The vessel size distribution on the lane.

Additional data may be attached to the lane, such as: the hull type distribution (single hull, double hull, etc) for tankers; the loading type (full loading, hydrostatic loading) for tankers; ship type etc..

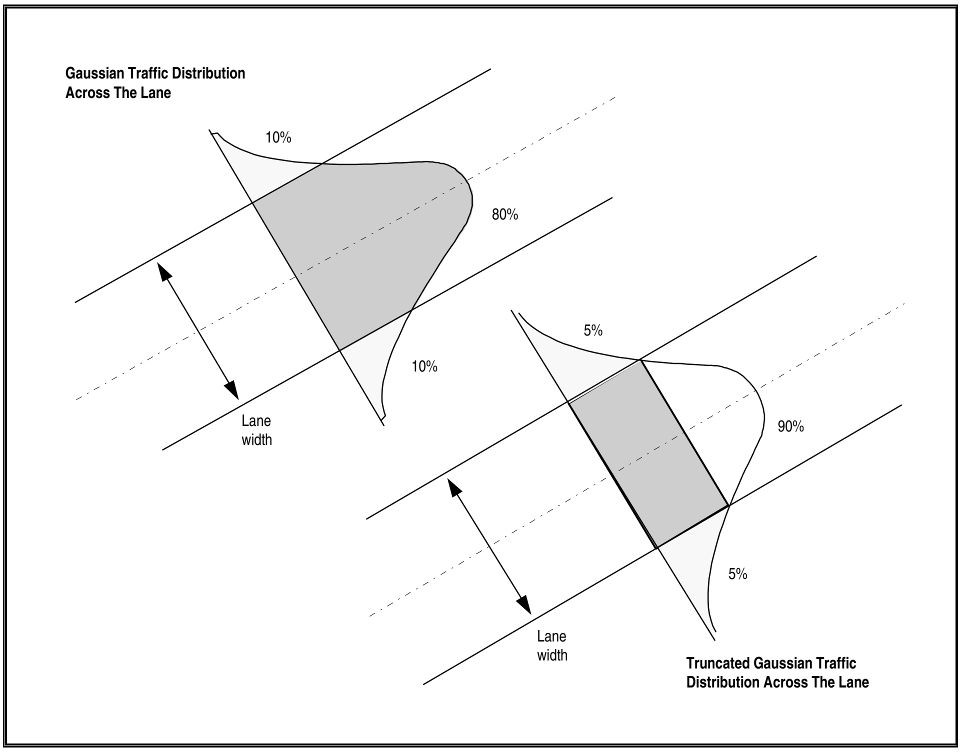
Figure I.5 Shipping Lane representation used in MARCS



Detailed surveys of marine traffic in UK waters in the mid 1980s (e.g. HMSO, 1985) concluded that commercial shipping follows fairly well defined shipping lanes, as opposed to mainly random tracks of individual ships. Further detailed analysis of the lanes showed that the lateral distribution across the lane width was approximately Gaussian, or truncated

Gaussian for traffic arriving in coastal waters from long haul voyages (e.g. from the US or Canada). The shipping lane distributions used in MARCS are shown in Figure I.6.

Figure I.6 Shipping Lane Width Distribution Functions used in MARCS



The marine traffic description used by MARCS is completed by the definition of four additional parameters for each type of traffic:

1. Average vessel speed (generally 8 to 18 knots);
2. Speed fraction applied to faster and slower than average vessels (generally plus/minus 20%);
3. Fraction of vessels travelling faster and slower than the average speed (generally plus/minus 20%);
4. Fraction of vessels that exhibit "rogue" behaviour (generally set to 0%, though historical accident data in many geographical areas shows a small proportion of (usually) smaller vessels undergo accidents through lack of watch keeping (bridge personal absent or incapacitated)).

A rogue vessel is defined as one that fails to adhere (fully or partially) to the Collision Avoidance Rules (Cockcroft, 1982). Such vessels are assumed to represent an enhanced collision hazard. These four parameters can be specified as a function of location within the study area for each traffic type.

The marine traffic image is made up by the superposition of the defined traffic for each contributing traffic type.

I.3.2 Internal Operational Data

Internal operational data is represented within MARCS using either worldwide data or frequency factors obtained from fault tree analysis or location specific survey data. Fault tree parameters take into consideration factors such as crew watch-keeping competence and internal vigilance (where a second crew member, or a monitoring device, checks that the navigating officer is not incapacitated by, for example, a heart attack). Examples of internal operational data include:

1. The probability of a collision given an encounter;
2. The probability of a powered grounding given a ship's course is close to the shoreline;
3. The frequency (per hour at risk) of fires or explosions.

Internal operational data may be defined for different traffic types and/ or the same traffic type on a location specific basis.

I.3.3 External Operational Data

External operational data generally represents controls external to the traffic image, which affect marine risk. In MARCS it relates mainly to the location of VTS zones (which influence the collision and powered grounding frequencies by external vigilance, where external vigilance means that an observer external to the ship may alert the ship to prevent an accident) and the presence and performance of emergency towing vessels (tugs) which can save a ship from drift grounding.

I.3.4 Environment Data

The environment data describes the location of geographical features (land, offshore structures etc.) and meteorological data (visibility, wind rose, sea currents and seastate).

Poor visibility arises when fog, snow, rain or other phenomena restricts visibility to less than 2 nautical miles. It should be noted that night-time is categorised as good visibility unless fog, for example, is present.

Windrose data is defined within 8 compass points (north, north-east, east etc) in 4 wind speed categories denoted: calm (0 – 20 knots); fresh (20 to 30 knots); gale (30 to 45 knots); and storm (greater than 45 knots). Seastate (wave height) within MARCS is inferred from the windspeed and the nature of the sea area (classified as sheltered, semi-sheltered or open water).

Sea currents are represented as maximum speeds in a defined direction within an area.

I.4 DESCRIPTION OF ACCIDENT FREQUENCY MODELS

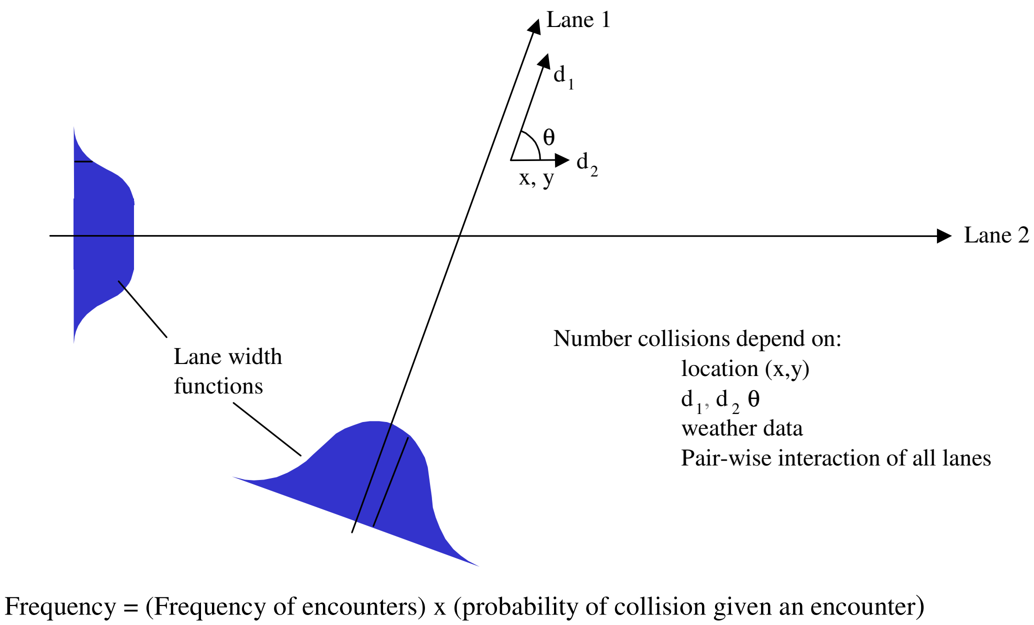
The section describes how MARCS uses the input data (traffic image, internal operational data, external operational data and environment data) to calculate the frequency of serious accidents in the study area.

I.4.1 The Collision Model

The collision model calculates the frequency of serious inter-ship powered collisions at a given geographical location in two stages. The model first estimates the frequency of encounters (critical situations for collision - when two vessels pass within 0.5 nautical miles of each other) from the traffic image data using a pair-wise summation technique, assuming no collision avoiding actions are taken. This enables the calculation of either total encounter frequencies, or encounter frequencies involving specific vessel types.

The model then applies a probability of a collision for each encounter, obtained from fault tree analysis, to give the collision frequency. The collision probability value depends on a number of factors including, for example, the visibility or the presence of a pilot. Figure I.7 shows a graphical representation of the way in which the collision model operates.

Figure I.7 Graphical representation of the collision model



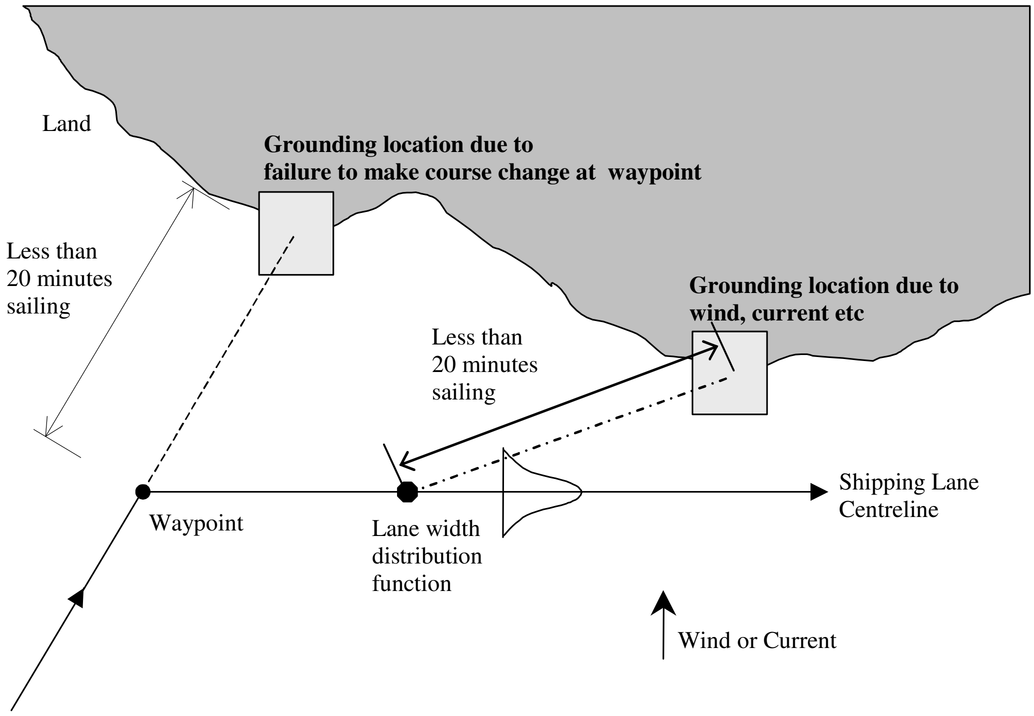
In Figure I.7, d_1 refers to the density of traffic associated with lane 1 at the location x,y. The frequency of encounters at location x,y through the interaction of lanes 1 and 2 is proportional to the product of d_1, d_2 and the relative velocity between the lane densities.

I.4.2 The Powered Grounding and Powered Collision Models

The powered grounding frequency model calculates the frequency of serious powered grounding accidents in two stages. The model first calculates the frequency of critical situations (sometimes called "dangerous courses" for powered grounding accidents). Two types of critical situation are defined as illustrated in Figure I.8. The first critical situation arises when a course change point (waypoint) is located such that failure to make the course change would result in grounding within 20 minutes navigation from the planned course change point if the course change is not made successfully. The second critical situation results when a grounding location is within 20 minutes navigation of the course centreline. In this case crew inattention combined with wind, current or other factors could result in a powered grounding.

The frequency of serious powered groundings is calculated as the frequency of critical situations multiplied by the probability of failure to avoid grounding.

Figure I.8 Graphical representation of the powered grounding model



The powered grounding probabilities are derived from the fault tree analysis of powered grounding. The powered grounding fault tree contains 2 main branches:

1. Powered grounding through failure to make a course change whilst on a dangerous course. A dangerous course is defined as one that would ground the vessel within 20 minutes if the course change were not made.
2. Powered grounding caused by crew inattention and wind or current from the side when the ship lane runs parallel to a shore within 20 minutes sailing.

Both these branches are illustrated in Figure I.8. The powered grounding frequency model takes account of internal and external vigilance, visibility and the presence of navigational aids (radar) in deducing failure parameters.

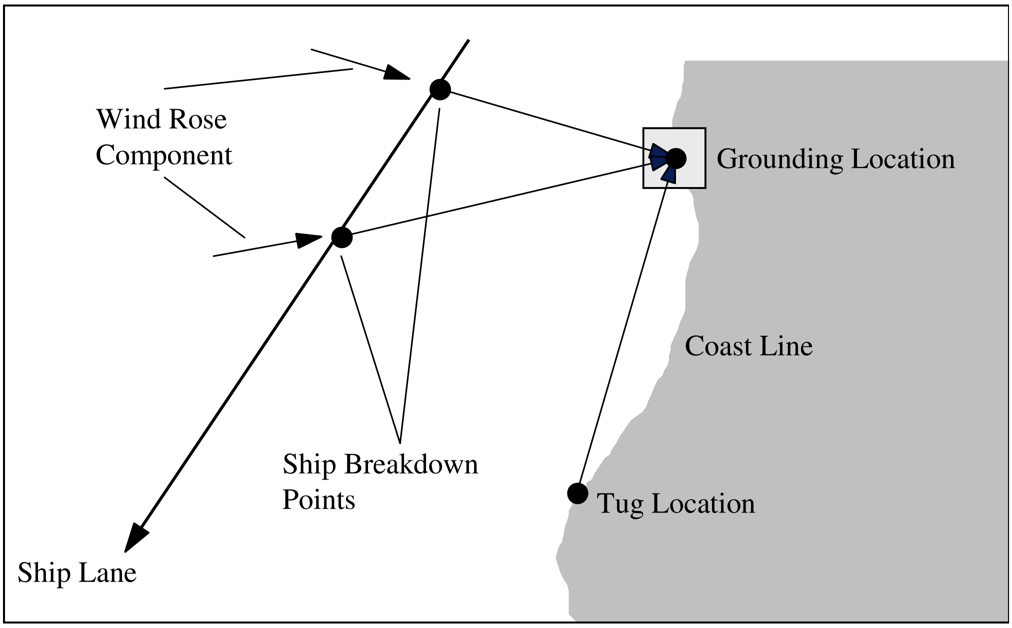
The powered collision with fixed objects model works is similar to the powered grounding model.

I.4.3 The Drift Grounding and Drift Collision Models

The drift grounding frequency model consists of two main elements as follows: first, the ship traffic image is combined with the ship breakdown frequency factor to generate the location and frequency of vessel breakdowns; second, the recovery of control of drifting ships can be regained by one of 3 mechanisms: a) repair, b) emergency tow assistance, or c) anchoring. Those drifting ships that are not saved by one of these three mechanisms (and do not drift out into the open sea) contribute to the serious drift grounding accident frequency results.

The number and size distribution of ships which start to drift is determined from the ship breakdown frequency, the annual number of transits along the lane and the size distribution of vessels using the lane. The proportion of drifting vessels which are saved (fail to ground) is determined from the vessel recovery models. The drift grounding frequency model is illustrated in Figure I.9.

Figure I.9 Graphical representation of the drift grounding model

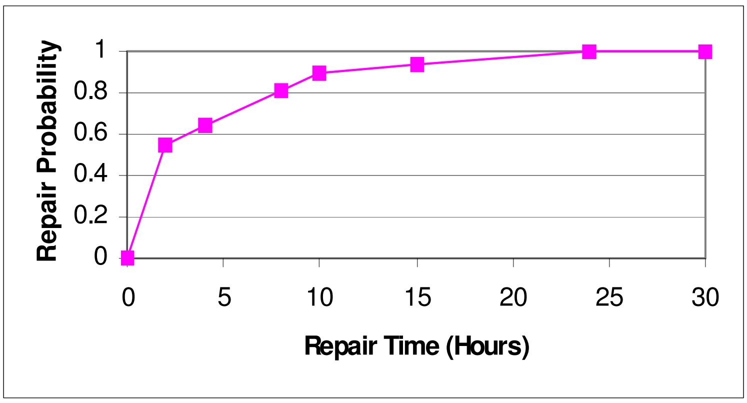


Implicit in Figure I.9 is the importance of the time taken for the ship to drift aground. When this time is large (because the distance to the shore is large and/ or because the drift velocity is small) then the probability that the ship will recover control before grounding (via repair or tug assistance) will be increased.

Repair Recovery Model

Vessels which start to drift may recover control by effecting repairs. For a given vessel breakdown location, grounding location and drift speed there is a characteristic drift time to the grounding point. The proportion of drifting vessels which have recovered control by self-repair is determined from this characteristic drift time and the distribution of repair times.

Figure I.10 Graphical representation of the self repair save mechanism



Recovery of Control by Emergency Tow

Drifting vessels may be brought under control (saved from grounding) by being taken in tow by an appropriate tug. It should be noted that the tug save model assumes a save is made when the ship is prevented from drifting further towards the shoreline by the attachment of a suitable tug. In practice, two or more tugs would be required to complete the ship save, by towing the vessel to a safe location, but this aspect of the save is not modelled in MARCS.

Two types of tug can be represented within MARCS. Close escort tugs move with ships through their transit, thus their time to reach a drifting ship is always small. Pre-positioned tugs are located at strategic points around the study area. The model works by calculating for each tug:

- If the tug can reach the drifting vessel in time to prevent it grounding. This time consists of the time to reach the ship (almost zero when close escorting) and the time to connect and take control of the ship (which is a function of seastate);
- If the tug can reach the ship before it grounds, then the adequacy of the tug with regard to control of the ship is evaluated. (The presence of several tugs of differing power is assumed to be represented by the presence of one tug of the largest power. This is because only one tug is usually used to exert the main "saving" pull. Other tugs present are used to control the heading of the disabled ship, and to bring the ship to a safe location.)
- When several tugs of various capabilities can reach the drifting ship in time, then the tug with the best performance is assumed to be connected to the ship and takes control of the largest proportion of the drifting vessels.

The tug model contains parameters to take explicit account of:

- The availability of the tug (some tugs have other duties);
- The tugs response time (delay before assistance is summoned);
- The tug speed (as a function of seastate);
- The time to connect a line and exert a controlling influence on the ship (as a function of seastate);
- The performance of the tug (identified as the maximum control tonnage for the tug) as a function of wind speed and location (since the wind speed and the fetch control sea state).

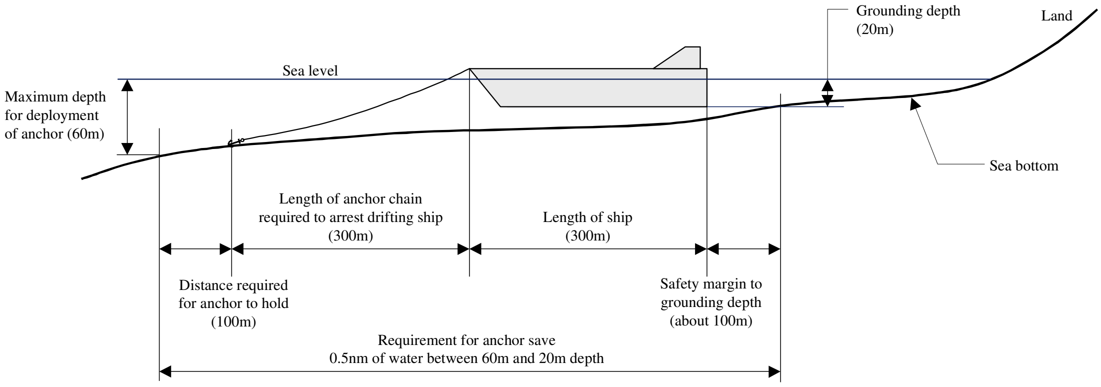
Tug performance parameters can take account of ship wind and wave resistance, tug wind and wave resistance and tug length and propulsion arrangement (open versus nozzle) which influences the propulsion efficiency.

Recovery of Control by Anchoring

The anchor save model is derived with reference to the following reasoning:

1. Anchoring is only possible if there is a sufficient length of suitable water to prevent the ship running aground. Suitable water is defined as a depth of between 30 fathoms (about 60m - maximum for deployment of anchor) and 10 fathoms (about 20m - minimum for ship to avoid grounding). Sufficient length is calculated as 100m for anchor to take firm hold of the seabed + 300m to stop ship + 300m for length of ship + 100m for clearance = 800m, or 0.5 nautical miles (to be slightly conservative).
2. If such a track exists, then the probability that the anchor holds is calculated as a function of the wind speed and the sea bottom type (soft sea beds consist predominantly of sands, silts and muds). If the anchor hold, then an anchor save is made.

Figure I.11 Graphical representation of the Anchor save mechanism



The anchor save model can also specify a time required to deploy the anchoring system as this may be significant for ships without main power.

The anchor save model is conservative in that it under-predicts the effectiveness of this save mechanism for average and smaller ships.

The drift collision with fixed objects model works is similar to the drift grounding model.

I.4.4 The Structural Failure Model

The structural failure/foundering accident frequency model applies accident frequency parameters derived from accident data or fault tree analysis with calculations of the ship exposure time to obtain the serious accident frequency. The structural failure/foundering parameters take account of the greater structural strength of some hull designs, such as double hulled vessels.

The total ship exposure time (number of vessel hours) in any area for a given wind speed category (used by MARCS to infer the seastate) can be calculated from the traffic image parameters (locations of lanes, frequencies of movements and vessel speeds) and the local wind speed parameters. The serious structural failure/foundering frequency is then obtained by multiplying these vessel exposure times by the appropriate structural failure frequency factor for the wind speed (seastate) category.

I.4.5 The Fire and Explosion Model

The fire/explosion accident frequency model applies the accident frequency parameters derived from accident data or fault tree analysis with calculations of the ship exposure time to obtain the serious accident frequency. The total ship exposure time (number of vessel hours) in any area can be calculated from the traffic image parameters (locations of lanes, frequencies of movements and vessel speeds). The fire/explosion serious accident frequency is then obtained by multiplying these vessel exposure times by the appropriate fire/explosion frequency factor (accidents per ship-hour). It should be noted that fire/explosion frequency factors assumed to be independent of environmental conditions outside the ship.

I.5 DESCRIPTION OF ACCIDENT CONSEQUENCE MODELS

I.5.1 Introduction

MARCS evaluates the consequences of an accident in terms of, for example, the loss of containment of any fluid stored within a ship. This loss of containment can be in the form of either a bunker (fuel) oil spillage, a loss of liquid cargo stored in atmospheric tanks (tanks at the same pressure as the atmosphere), or a loss of gas cargo from pressurised or refrigerated tanks. It should be noted that MARCS does not calculate any consequences based upon the dispersion of fluid that might result from a loss of containment, though DNV is able to assess such consequences using other DNV tools.

Marine accident consequences are typically expressed in terms of cargo spilled, lives lost or financial loss. They are used with the frequency of a marine accident to estimate the resulting marine accident risk(s).

I.5.2 Factors affecting Cargo Loss Risk

There are various factors or events that can affect the risk of loss of containment following an accident ranging from those that relate to accident frequencies to those that relate to accident locations. Listed below are the factors which may be referenced by MARCS, depending on the situation, when evaluating the consequence(s) of a particular scenario.

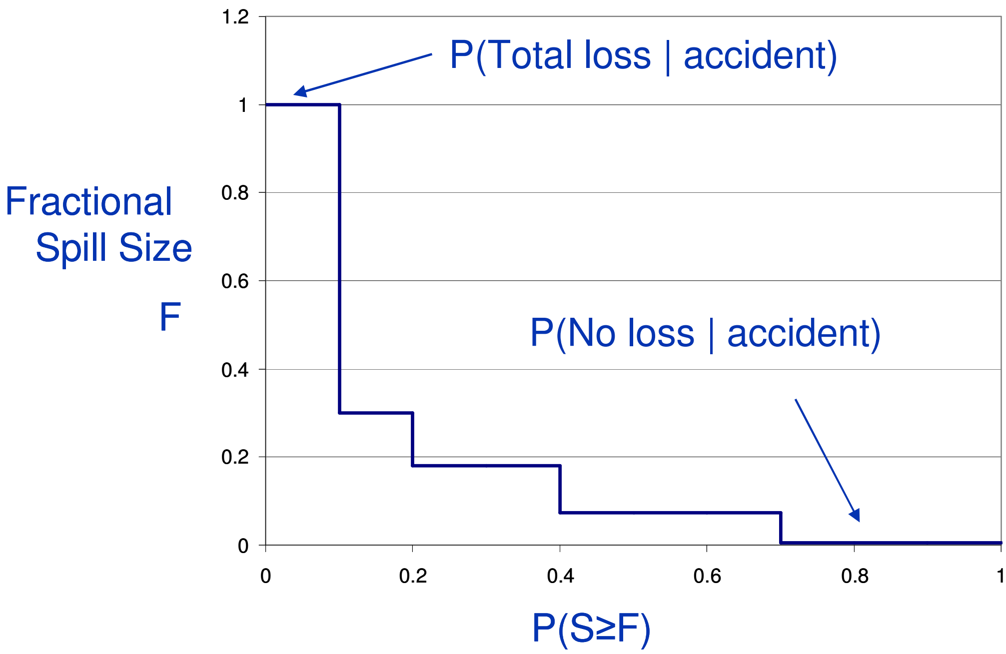
- Frequency of serious accidents. This is taken from the accident frequency models based upon historical accident data, as described in Section IV.4 above, and is one of the main factors that affect risk.
- The probability of loss of containment given a serious accident. This could be a function of:
    - Ship Type. A laden crude tanker has both cargo and bunker oil that could spill compared with, for example, a container ship that has only bunker oil.
    - Ship Structure. Ships may be single or double hulled, or a variation of either.
    - Probability of grounding on rocks. Grounding on rocks will increase the likelihood of a loss of containment.
    - Severity of accident. For example, an increase in the momentum of a colliding ship will increase the severity of an accident because of the resulting increase in energy that needs to be dissipated.
    - Location of accident. For example, high wave energy shore lines lead to an increased risk of ship damage during grounding and hence increased risk of loss of containment or, if the loss of containment has already occurred, then an increased risk in total loss of the ship.
- Probability of outflow of a specific quantity given a serious accident. This is the probability that there is a spillage of certain mass following a serious accident.
- Probability of the total loss of a ship given a serious accident. This assumes a total loss of cargo, though in practice some cargo may be recovered without spillage or without total spillage.

I.5.3 Generic Spill Model

The spill models developed for use by MARCS are based upon one or more of 3 main sources of information. These are historical accident analysis, engineering calculations, and judgements based upon other sources of data. Historical accident analysis, where available, can provide information on the number of accidents per ship category and the size of spillage in each case. This is usually the most robust source of data and is often complemented by further calculations to obtain spill models. In certain cases it is necessary to make judgements where relevant data is lacking; this can be the least robust method available.

Previous projects performed by DNV have developed crude oil outflow models for different accident types (collision, fire/explosion etc) and different hull configurations (single hull, double hull etc). These models (normalised cumulative probability distributions) take the generic form shown in Figure IV.12. This shows a typical spill model as used by MARCS. The fractional spill size is defined as the size of the spillage divided by the total cargo capacity of the ship in DWT and the value on the x-axis is the probability that an actual spill (as a fraction of the total capacity) is greater than a certain defined fractional spill size.

Figure I.12 Generic MARCS Spill Model



DNV has also developed bunker fuel oil spill models for all ship types, using a similar form to that shown in Figure IV.12. It should be noted that, in general, double hulled ships do not have “double skin” protection for their bunker fuel.

I.5.4 MARCS Spill Model Parameters

There are various parameters that MARCS utilises to reference a particular spill model in order to correctly estimate the marine accident risks. These are listed below along with examples:

- Accident Type. For example, collision, powered grounding, etc.
- Vessel Type and Size. For example, oil tanker with a cargo capacity of 100,000 DWT.
- Accident Severity. For example, collision energy.
- Accident Location. For example, high wave energy shore line.
- Hull Type. For example, single hull, double hull, double bottom, double side.
- Loading Type. For example, fully laden, part laden, empty (contains bunker oil only).
- Probability of vessel being laden for each cargo type. For example, a vessel might be laden 50% of the time and empty the other 50% of the time resulting in the vessel having a 0.5 probability of being laden.

These parameters are used to access the correct spill model in MARCS.

I.6 REFERENCES

Cockcroft, 1988: "A guide to the collision avoidance rules", Cockcroft, A N and Lameijar J N F, Stanford Maritime, 1982.

Cooke R.M., 1995: "Methods and Code for Uncertainty Analysis", UNICORN, AE Technology, TUDelft,

Henley E.J., Kumamoto H., 1981: "Reliability Engineering and Risk Assessment", Prentice-Hall Inc.

HMSO, 1985: "Shipping routes in the area of the UK continental shelf: Offshore technology report", OTH 85 213, HMSO, March 1985.

SAFECO I: "Safety of Shipping in Coastal Waters (SAFECO I) Summary Report", DNV 98-2038, 1998.

SAFECO II: "Safety of Shipping in Coastal Waters (SAFECO II) Summary Report", DNV 99-2032, 1999.

Appendix 5   Data input in MARCS

Contents

II. DATA USED BY THE MARCS MODEL

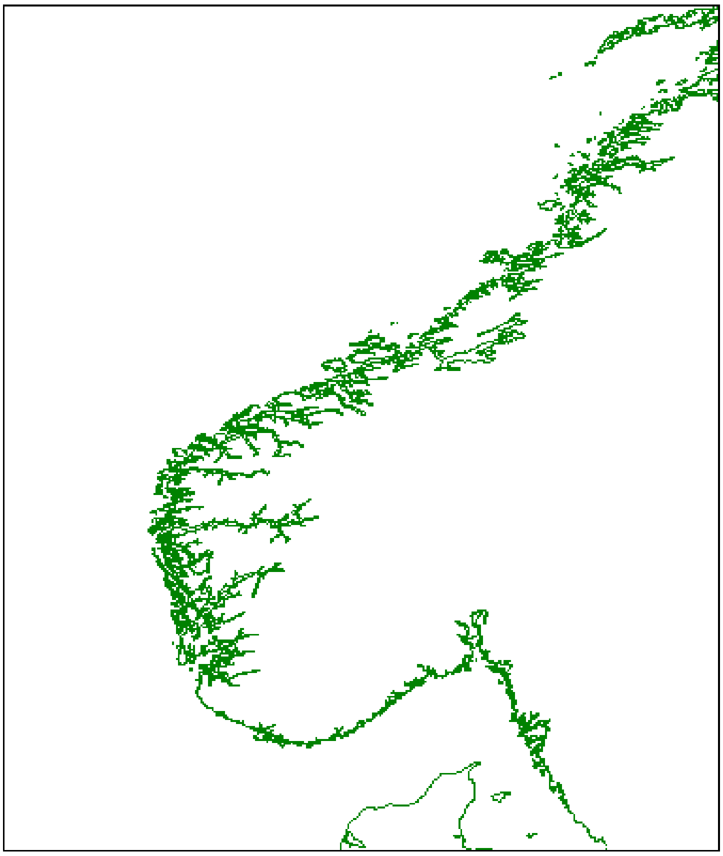
This appendix describes the data and reasoning behind the risk analysis parameters used to generate the marine risk results used in this project.

II.1 RISK MODELLING APPROACH

This section describes the overall approach to the modelling of the risks of alternative tanker routings off the coast of Norway. The marine risk model (MARCS, or Marine Accident Calculation System) is described in detail in Appendix I.

The study area is shown in Figure II.1. This has been chosen so that all ship routes within 50nm (nautical miles) of the Norwegian coast are included within the study area. This limit is selected because in previous marine projects performed by DNV it has been judged that 50nm is the highest credible drift distance for a mechanically disabled ship. It should be noted that any ships outside the defined study area cannot influence the marine risk analysis, or the risk results obtained.

Figure II.1 Definition of the Project Study Area



The co-ordinates of the study area are between 68^{o} 30’ and 56^{o} 30’ north to south and between 2^{o} and 15^{o} west to east. The calculation resolution is 1 minute by 1 minute; each small area defined by the calculation resolution is called a calculation location, see Appendix I.

Other inputs that contribute to the definition of the project study area, such as the location of offshore wind turbines and the location of the grounding line, are described in Section II.4 below.

II.2 MARINE TRAFFIC IMAGE DATA

II.2.1 Traffic Characteristics

MARCS represents marine traffic in terms of up to 8 traffic types and traffic routes for each traffic type. For most projects, traffic types are defined in terms of the similarity of risks that each ship type poses and other similarities (for example, ferries tend to trade faster so may be grouped separately from general cargo ships). Non-hazardous traffic types, such as general cargo ships, container ships and ferries will also be defined. This is because these non-hazardous ships can collide with hazardous cargo ships, and because all ships carry bunker oil. In this study NCTR were responsible for the collection of ship traffic data.

The traffic types defined in this study are as follows:

- Type 1: Chemical tankers and refined product tankers;
- Type 2: Gas tankers;
- Type 3: Oil (crude) tankers;
- Type 4: Not used;
- Type 5: Not used;
- Type 6: Cargo > 5000bt;
- Type 7: Other >5000bt;
- Type 8: All other.

For each ship lane defined it is necessary to define a range of parameters which describe:

- The lane number and ship type (as above);
- The cargo type that is being transported (see below);
- The annual frequency of ship movements along the lane (ships/year);
- The lane type (all lanes in this study are one-way Gaussian – see Appendix I);
- Any tug escorts that may be present (none in this study);
- The type of ship loading (characterised by 3 parameters);
- The proportion of ships on the lane in each ship size (DWT) and hull type (single hull, double hull etc) category;
- The number of waypoints, the location of each waypoint and the lane width (twice the standard deviation) at each waypoint.

These parameters are provided in the spreadsheet NCTRInput 12Oct09.xls. Four traffic patterns were defined as follows:

- “Gammel2008”. Shipping traffic prior to deep water routing for the year 2008. This is denoted as Case A.
- “Ny2008”. New shipping traffic after the implementation of deep water routing for the year 2008. This is denoted as Case B.
- “Gammel2025”. Estimated shipping traffic prior to deep water routing for the year 2025. This is denoted as Case C.
- “Ny2008”. Estimated new shipping traffic after the implementation of deep water routing for the year 2025. This is denoted as Case D.

The cargo type carried by each vessel type corresponds to the traffic type in this project. That is, chemical tankers carry chemicals (assumed to be hydrocarbons and immiscible with sea water), gas carriers contain hydrocarbon gases, oil tankers carry crude oil. The remaining traffic types do not carry hazardous cargo that is within the scope of this work.

In addition, it is assumed that all ships carry bunker fuel oil in their bunker fuel oil tanks (distinct from bunker fuel oil as a cargo). Spills of bunker oil are within the scope of this work.

II.2.2 Internal Operational Data

In DNV's previous marine risk analysis projects we have derived internal operational data, such as ship-ship collision probabilities given an encounter, from North Sea fleet data. This is assumed to apply to marine traffic in Norwegian waters. Table II.1 shows the internal operational data which DNV normally applies for North Sea average ships [DNV, 1997; DNV, 1998].

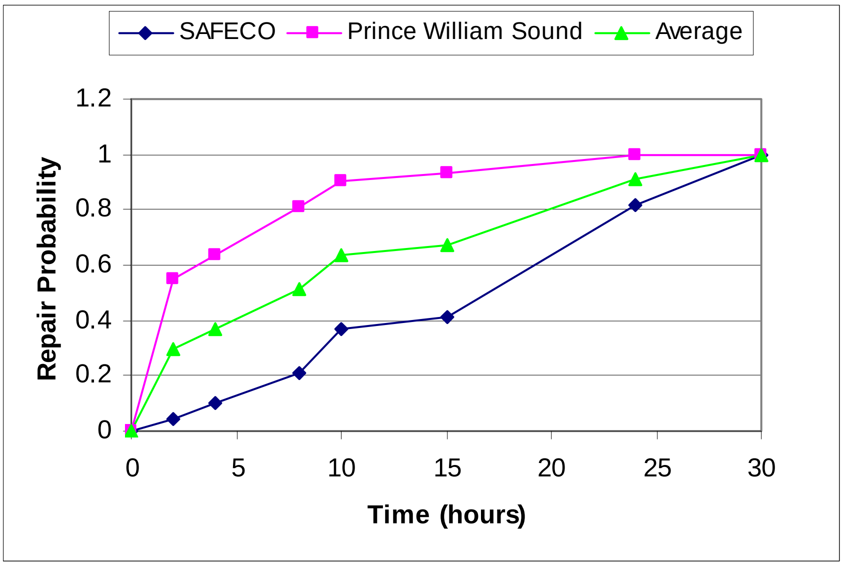
Table II.1 Risk Parameters for North Sea Average Ships

Risk Parameter		**Average ship probability (all ship types)**
Accident Type	**Visibility**	
Collision with VTS support	Good	6.83e-5
Collision with VTS support	Poor	4.64e-4
Powered Grounding with VTS support	Good	2.47e-4
Powered Grounding with VTS support	Poor	6.87e-4

Accident Type and Parameter Description	**Ship Type**	**Average ship frequency (per hour)**
Drift Grounding Ship breakdown frequency per hour	Type 1: Chemical tankers; Type 2: Gas tankers; Type 3: Oil (crude) tankers; Type 6: Cargo > 5000bt; Type 7: Other >5000bt; Type 8: All other.	2.50e-4 2.50e-4 2.50e-4 2.50e-4 2.50e-4 2.50e-4
Structural Failure Structural failure frequency per hour in calm/ fresh, gale and storm seastates respectively	Type 1: Chemical tankers; Type 2: Gas tankers; Type 3: Oil (crude) tankers; Type 6: Cargo > 5000bt; Type 7: Other >5000bt; Type 8: All other.	4.62e-7 4.62e-7 9.23e-7 4.62e-7 4.62e-7 9.23e-7 4.62e-7 4.62e-7 9.23e-7 4.62e-7 4.62e-7 9.23e-7 4.62e-7 4.62e-7 9.23e-7 4.62e-7 4.62e-7 9.23e-7
Fire/Explosion	Type 1: Chemical tankers; Type 2: Gas tankers; Type 3: Oil (crude) tankers; Type 6: Cargo > 5000bt; Type 7: Other >5000bt; Type 8: All other.	4.08e-7 4.08e-7 4.08e-7 4.08e-7 4.08e-7 4.08e-7

Figure II.2 shows the distribution of self-repair times derived from these two projects (Prince William Sound Risk Assessment and SAFECO respectively). As shown in Figure II.2, there is considerable uncertainty regarding the time required to repair mechanical failures onboard ship. In the current project the average curve from both projects is assumed to apply to all ships.

Figure II.2 Self Repair Distribution Function used in SAFECO project and used in Prince William Sound (PWS) project and the average of both curves used in this project



II.2.3 Traffic speeds

Table II.2 shows the average speed of each vessel type in the study area as used in the risk calculation. This speed is uniform throughout the study area.

Table II.2 Average Vessel Speed (knots) applied in the Study Area

Ship Type	All Locations (knots)
Type 1: Chemical tankers;	12
Type 2: Gas tankers;	12
Type 3: Oil (crude) tankers;	12
Type 6: Cargo > 5000bt;	12
Type 7: Other >5000bt;	12
Type 8: All other.	12

II.3 EXTERNAL OPERATIONAL DATA FOR STUDY AREA

The support of Vessel Traffic Service (VTS) can reduce the frequency of collision, powered grounding and powered collision with fixed obstacles due to the additional surveillance provided. In this study the entire study area is assumed to be supported by VTS and the accident parameters shown in Table II.1 are applied.

Table II.3 summarises the emergency tows which are potentially available (data from NCTR, see NCTRInput 12Oct09.xls, sheet Tugs). Tugs with bollard pull less than 40 tonnes are assumed to have insignificant capability of taking control of ships in the open sea.

Table II.3 Locations and Performances of Emergency Tows

Location	North	East	Number	Bollard pull (tonne)
Oslo/Brevik	59°22`	9°41`	5	< 40
Kristiansand	58°08`	7°59`	1	< 40
Farsund	58°03`	6°44`	1	< 40
Kårstø	59°17`	5°31`	1	42- 50
Slagentangen	59°19`	10°31`	1	53
Sture	60°38`	4°49`	1	53- 92
Stavanger	58°57`	5°43`	3	43-90
Bergen	60°23`	5°19`	1	64
Mongstad	60°48`	5°02`	1	53-95
Kristiansund	63°07`	7°41`	2	< 40
Trondheim	63°26`	10°23`	2	< 40
Ålesund	62°28`	6°05`	3	< 40
Sandnessjøen	66°01`	12°36`	1	50
Narvik	68°23`	17°41`	2	43-47

Due to the high levels of traffic in the area, it is possible that other tugs or salvage vessels might fortuitously be in the vicinity of a drifting ship and therefore be able to offer assistance. This eventuality has not, however, been included in the drift grounding frequency calculator within MARCS, to ensure that a conservative approach to the risk modelling is maintained throughout the study.

The tug input data to the MARCS model is shown in Table II.4. Each tug type in Table II.3 is assigned to a tug performance class by reference to previous tug performances characterised by DNV. The availability of each tug is determined by assuming that each individual tug is available for only 20% of the time. Thus the availability for controlling a drifting vessel is estimated from the equation:

$$\text{Availability} = 1.0 - 0.8^{(\text{number of tugs of similar performance at the location})}$$

Table II.4 Tug Input Data

Class	Availability	N	E
1	0.488	59.28333	17.08333
1	0.200	59.31667	19.16667
1	0.360	60.63333	38.06667
3	0.200	60.63333	38.06667
1	0.360	58.95000	57.08333
3	0.200	58.95000	57.08333
3	0.200	60.80000	48.08333
2	0.200	60.80000	48.08333

1	0.360	60.8000 0	48.0833 3
1	0.200	66.0166 7	1.20000
1	0.360	68.3833 3	23.2833 3

As noted above, tugs with less than 40 tons of bollard pull are judged to be ineffective in open water.

The performance (speed of the tug and the maximum size of ship it can control in kdwt) of each tug type, taken from previous work by DNV, is shown in Table II.5.

Table II.5 Tug Performance Data for a Open Sea Location (Save = Maximum size of ship in kdwt that can be controlled by the tug in the specified conditions)

Wind	**Calm**				**Fresh**			
	Speed knots	**Save**	**Speed knots**	**Save**	**Speed knots**	**Save**	**Speed knots**	**Save**
Type 1	14	999	11	999	8	0	5	0
Type 2	14	999	11	999	8	0	5	0
Type 3	14	999	11	999	8	49	5	0
Type 4	14	999	11	999	8	142	5	0
Type 5	14	999	11	999	8	999	5	147

The locations of 157 offshore oil platforms were included in the risk assessment. The data used is recorded in spreadsheet NCTRInput 12Oct09.xls, sheet Platforms.

II.4 ENVIRONMENTAL DATA FOR THE STUDY AREA

Typical values of visibility and wind speed/ direction for the North Sea from a previous project were used in this project as shown in Tables II.7 and II.8.

Table II.7 Visibility Data used in this Project

Sea Area	**Good Visibility (time fraction greater than 2 nm)**	**Poor Visibility (time fraction less than 2 nm)**	**Data Source**
North Sea Average	0.95	0.05	DNV, 1998
Data applied in this study	0.95	0.05	

Table II.8 Windrose Data for the Study Area (DNV, 1998)

Wind State	**Wind speed (knots)**	**Wind Direction - North Sea Average (DNV, 1998)**							
		N	NE	E	SE	S	SW	W	NW
Calm	0 – 20	0.058	0.028	0.042	0.053	0.090	0.090	0.08	0.08
Fresh	20 – 30	0.029	0.014	0.021	0.027	0.045	0.045	0.04	0.04
Gale	30 - 45	0.023	0.011	0.017	0.021	0.036	0.036	0.032	0.032
Storm	> 45	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002

The significant wave height observed is a function of the wind speed, the time for which that wind speed has been observed and the "fetch" of the location (the sea distance over which the wind acts and the wave heights are built). In previous work (DNV, 1997), DNV defined 3 types of sea location and approximate significant wave heights as a function of wind speed, as shown in Table II.9. Within Table II.9, the "Open Ocean" location considered was the northern Pacific Ocean (i.e. a large body of water with some very large waves).

Table II.9 Approximate Significant Wave Height as a function of Wind Speed and Location Characteristics

Wind State	Wind Speed	Sheltered Wave Height	Semi-Sheltered Wave Height	Open Ocean Wave Height
Calm	20 knots	1.2m	1.6m	2m
Fresh	30 knots	2.4m	3.2m	4m
Gale	45 knots	4.2m	5.6m	7m
Storm	58 knots	5.4m	7.2m	9m

In order to be conservative, the study area in this project was characterised as open ocean, as the Norwegian Sea cannot be considered to be semi-sheltered.

The navigation charts were examined for sea current data but no significant currents were found (excluding tidal currents which cannot be represented adequately by a statistical model such as MARCS) and so none were included in the risk analysis calculations.

The grounding line for the marine traffic was assumed to be the same as the coastline in this project. That is, the sea depth increases rapidly as distance from the coastline increases.

The sea bottom and shoreline that predominates within the study area is mainly rock. Thus, in the case of grounding, the probability of a cargo or fuel oil release is relatively high compared to a sandy or muddy sea-bottom or shoreline. Thus a uniform probability of a cargo spill (or more precisely a puncture of the outer hull) given a grounding of 1.0 is applied throughout the study area. (Note that this probability does not take account of additional risk controls. For example, if a tanker is double hulled a spill may not always result from grounding on rocks.)

A drifting ship can save itself from grounding by deploying its anchoring systems, provided that the sea bottom geometry is suitable. For anchor saves to be effective, the sea depth should lie between 60 and about 20m for a distance of half a nautical mile, see Appendix I. Anchor saves are more effective at low wind speeds and for softer sea bottoms. In this study area it was assumed that anchoring would be an ineffective save mechanism at all locations in the study area.

II.5 REFERENCES

DNV, 1997: "Prince William Sound Risk Assessment", Final Report to the Prince William Sound risk assessment steering committee, December 1996.

DNV, 1998: "Demonstration of risk analysis techniques for ship transportation in European waters", Report 98-2021, Final report to SAFECO project.

Appendix 6 MARCS results

The different table categories have been given the following colour keys:

(white)	Accident frequency per year
(light cyan)	Spilling accident frequency per year
(blue)	Oil spill volumes in tonnes per year

Today's route 2008

All accidents

	Total	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	2.23E-01	2.40E-02	1.43E-02	1.07E-02	3.21E-02	1.29E-02	1.29E-01
Struc	1.32E-01	1.42E-02	8.34E-03	6.56E-03	1.91E-02	7.59E-03	7.66E-02
FEX	1.16E-01	1.24E-02	7.30E-03	5.74E-03	1.67E-02	6.63E-03	6.70E-02
PGrd	5.72E-01	7.23E-02	4.33E-02	3.61E-02	1.25E-01	8.26E-02	2.13E-01
DGrd	4.05E+00	4.14E-01	2.69E-01	1.44E-01	5.68E-01	2.15E-01	2.44E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	6.30E-06	6.00E-07	7.00E-07	0.00E+00	2.00E-06	0.00E+00	3.00E-06
Total	5.10E+00	5.37E-01	3.43E-01	2.03E-01	7.61E-01	3.25E-01	2.93E+00

Accidents with cargo oil spills

	Accident	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	3.84E-02	1.13E-02	4.93E-03	4.77E-03	3.21E-03	1.29E-03	1.29E-02
Struc	2.52E-02	8.40E-03	2.83E-03	3.65E-03	1.91E-03	7.59E-04	7.66E-03
FEX	2.20E-02	7.34E-03	2.48E-03	3.19E-03	1.67E-03	6.64E-04	6.70E-03
PGrd	1.25E-01	4.22E-02	1.91E-02	2.13E-02	1.25E-02	8.26E-03	2.13E-02
DGrd	6.61E-01	1.82E-01	9.65E-02	6.05E-02	5.68E-02	2.16E-02	2.44E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	5.70E-07	1.00E-07	1.60E-07	1.00E-07	1.00E-07	1.00E-08	1.00E-07
Total	8.71E-01	2.51E-01	1.26E-01	9.33E-02	7.61E-02	3.25E-02	2.93E-01

Cargo oil spill volumes

	Risk	Area:	2	North			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	8.92E+01	2.24E+01	1.45E+01	5.02E+01	1.20E+00	1.46E-01	7.52E-01
Struc	1.28E+02	3.51E+01	8.32E+00	8.33E+01	7.31E-01	8.55E-02	4.48E-01
FEX	8.20E+01	2.19E+01	7.28E+00	5.18E+01	6.39E-01	7.47E-02	3.92E-01
PGrd	4.69E+02	1.16E+02	4.71E+01	2.99E+02	4.57E+00	7.46E-01	1.34E+00
DGrd	1.25E+03	3.80E+02	2.77E+02	5.61E+02	1.90E+01	2.30E+00	1.39E+01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	4.30E-04	3.00E-05	3.80E-04	0.00E+00	0.00E+00	0.00E+00	2.00E-05
Total	2.02E+03	5.75E+02	3.54E+02	1.04E+03	2.61E+01	3.35E+00	1.69E+01

Proposed route 2008

All accidents

	Total	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.82E-01	1.47E-02	1.01E-02	6.93E-03	2.76E-02	9.89E-03	1.13E-01
Struc	1.42E-01	1.57E-02	9.45E-03	6.55E-03	2.54E-02	8.99E-03	7.63E-02
FEX	1.24E-01	1.37E-02	8.26E-03	5.73E-03	2.22E-02	7.87E-03	6.67E-02
PGrd	5.52E-01	6.62E-02	4.04E-02	3.42E-02	1.18E-01	8.01E-02	2.13E-01
DGrd	3.42E+00	2.25E-01	1.56E-01	7.90E-02	3.66E-01	1.43E-01	2.45E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	2.47E-03	6.15E-04	1.69E-04	4.76E-04	1.01E-03	2.00E-04	2.92E-06
Total	4.42E+00	3.36E-01	2.24E-01	1.33E-01	5.61E-01	2.50E-01	2.92E+00

Accidents with cargo oil spills

	Accident	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	2.83E-02	6.75E-03	3.46E-03	2.99E-03	2.76E-03	9.90E-04	1.13E-02
Struc	2.67E-02	8.93E-03	3.04E-03	3.63E-03	2.54E-03	8.99E-04	7.63E-03
FEX	2.33E-02	7.80E-03	2.66E-03	3.18E-03	2.22E-03	7.86E-04	6.67E-03
PGrd	1.20E-01	3.97E-02	1.82E-02	2.05E-02	1.18E-02	8.02E-03	2.13E-02
DGrd	4.86E-01	9.92E-02	5.71E-02	3.40E-02	3.66E-02	1.44E-02	2.44E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	1.99E-04	6.77E-05	1.87E-05	5.25E-05	5.03E-05	1.01E-05	9.61E-08
Total	6.84E-01	1.62E-01	8.45E-02	6.43E-02	5.60E-02	2.51E-02	2.91E-01

Cargo oil spill volumes

	Risk	Area:	2	North			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	6.32E+01	1.43E+01	1.03E+01	3.65E+01	1.27E+00	1.38E-01	6.75E-01
Struc	1.40E+02	4.06E+01	8.94E+00	8.84E+01	1.26E+00	1.30E-01	4.50E-01
FEX	8.97E+01	2.53E+01	7.81E+00	5.50E+01	1.11E+00	1.14E-01	3.93E-01
PGrd	4.56E+02	1.11E+02	4.42E+01	2.94E+02	4.37E+00	7.20E-01	1.34E+00
DGrd	7.42E+02	2.13E+02	1.66E+02	3.35E+02	1.24E+01	1.58E+00	1.40E+01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	3.13E-01	2.37E-02	3.04E-02	9.65E-02	1.56E-01	6.51E-03	1.94E-05
Total	1.49E+03	4.05E+02	2.38E+02	8.08E+02	2.06E+01	2.69E+00	1.68E+01

Today's route 2025

All accidents

	Total	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	3.81E-01	4.53E-02	9.27E-02	2.00E-02	5.00E-02	1.96E-02	1.53E-01
Struc	1.70E-01	2.06E-02	3.70E-02	9.45E-03	2.32E-02	9.19E-03	7.01E-02
FEX	1.48E-01	1.80E-02	3.24E-02	8.27E-03	2.03E-02	8.03E-03	6.12E-02
PGrd	7.00E-01	1.08E-01	9.72E-02	5.38E-02	1.49E-01	9.88E-02	1.93E-01
DGrd	5.10E+00	5.95E-01	1.11E+00	2.05E-01	6.88E-01	2.60E-01	2.24E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	8.10E-06	1.00E-06	2.10E-06	0.00E+00	2.00E-06	1.00E-06	2.00E-06
Total	6.49E+00	7.87E-01	1.37E+00	2.97E-01	9.31E-01	3.96E-01	2.72E+00

Accidents with cargo oil spills

	Accident	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	8.02E-02	2.12E-02	2.78E-02	8.92E-03	5.00E-03	1.96E-03	1.53E-02
Struc	3.88E-02	1.22E-02	1.12E-02	5.26E-03	2.32E-03	9.20E-04	7.00E-03
FEX	3.40E-02	1.06E-02	9.77E-03	4.60E-03	2.03E-03	8.04E-04	6.13E-03
PGrd	1.81E-01	6.30E-02	4.19E-02	3.18E-02	1.49E-02	9.89E-03	1.93E-02
DGrd	1.01E+00	2.62E-01	3.46E-01	8.67E-02	6.88E-02	2.60E-02	2.24E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	1.02E-06	2.00E-07	5.00E-07	1.00E-07	1.00E-07	2.00E-08	1.00E-07
Total	1.35E+00	3.69E-01	4.36E-01	1.37E-01	9.31E-02	3.96E-02	2.72E-01

Cargo oil spill volumes

	Risk	Area:	2	North			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	2.28E+02	4.20E+01	8.84E+01	9.50E+01	1.87E+00	2.27E-01	8.95E-01
Struc	2.09E+02	5.10E+01	3.54E+01	1.21E+02	8.85E-01	1.03E-01	4.10E-01
FEX	1.39E+02	3.17E+01	3.10E+01	7.54E+01	7.74E-01	9.04E-02	3.59E-01
PGrd	7.39E+02	1.74E+02	1.09E+02	4.49E+02	5.47E+00	8.92E-01	1.21E+00
DGrd	2.50E+03	5.49E+02	1.10E+03	8.06E+02	2.30E+01	2.77E+00	1.28E+01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	9.70E-04	4.00E-05	9.00E-04	0.00E+00	0.00E+00	1.00E-05	2.00E-05
Total	3.81E+03	8.47E+02	1.37E+03	1.55E+03	3.20E+01	4.08E+00	1.56E+01

Proposed route 2025

All accidents

	Total	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	2.81E-01	2.70E-02	5.24E-02	2.10E-02	4.50E-02	1.50E-02	1.20E-01
Struc	1.88E-01	2.18E-02	4.04E-02	1.36E-02	3.17E-02	1.08E-02	6.97E-02
FEX	1.64E-01	1.90E-02	3.53E-02	1.19E-02	2.77E-02	9.41E-03	6.09E-02
PGrd	6.62E-01	9.93E-02	8.08E-02	5.13E-02	1.41E-01	9.58E-02	1.93E-01
DGrd	3.76E+00	3.19E-01	4.33E-01	1.42E-01	4.51E-01	1.73E-01	2.24E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	4.71E-03	9.22E-04	1.73E-03	7.15E-04	1.12E-03	2.24E-04	2.93E-06
Total	5.06E+00	4.87E-01	6.44E-01	2.40E-01	6.98E-01	3.04E-01	2.69E+00

Accidents with cargo oil spills

	Accident	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	5.59E-02	1.29E-02	1.82E-02	6.73E-03	4.50E-03	1.50E-03	1.20E-02
Struc	4.33E-02	1.28E-02	1.36E-02	5.64E-03	3.17E-03	1.08E-03	6.96E-03
FEX	3.79E-02	1.12E-02	1.19E-02	4.93E-03	2.77E-03	9.42E-04	6.10E-03
PGrd	1.70E-01	5.96E-02	3.63E-02	3.08E-02	1.41E-02	9.59E-03	1.93E-02
DGrd	6.29E-01	1.44E-01	1.47E-01	5.21E-02	4.51E-02	1.73E-02	2.24E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	4.39E-04	1.02E-04	1.91E-04	7.81E-05	5.62E-05	1.12E-05	1.97E-07
Total	9.37E-01	2.41E-01	2.27E-01	1.00E-01	6.97E-02	3.04E-02	2.69E-01

Cargo oil spill volumes

	Risk	Area:	2	North			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.01E+02	1.59E+01	2.97E+01	5.41E+01	1.18E+00	1.14E-01	3.84E-01
Struc	1.30E+02	3.09E+01	2.24E+01	7.61E+01	7.98E-01	7.85E-02	2.11E-01
FEX	8.71E+01	1.92E+01	1.96E+01	4.74E+01	6.98E-01	6.86E-02	1.84E-01
PGrd	3.52E+02	8.35E+01	4.41E+01	2.21E+02	2.61E+00	4.30E-01	6.07E-01
DGrd	6.61E+02	1.58E+02	2.22E+02	2.66E+02	7.83E+00	9.59E-01	6.43E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	3.36E-01	1.77E-02	1.55E-01	7.26E-02	8.67E-02	3.63E-03	9.74E-06
Total	1.33E+03	3.08E+02	3.38E+02	6.65E+02	1.32E+01	1.65E+00	7.82E+00

Today's route 2008

All accidents

	Total	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	2.23E-01	2.40E-02	1.43E-02	1.07E-02	3.21E-02	1.29E-02	1.29E-01
Struc	1.32E-01	1.42E-02	8.34E-03	6.56E-03	1.91E-02	7.59E-03	7.66E-02
FEX	1.16E-01	1.24E-02	7.30E-03	5.74E-03	1.67E-02	6.63E-03	6.70E-02
PGrd	5.72E-01	7.23E-02	4.33E-02	3.61E-02	1.25E-01	8.26E-02	2.13E-01
DGrd	4.05E+00	4.14E-01	2.69E-01	1.44E-01	5.68E-01	2.15E-01	2.44E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	6.30E-06	6.00E-07	7.00E-07	0.00E+00	2.00E-06	0.00E+00	3.00E-06
Total	5.10E+00	5.37E-01	3.43E-01	2.03E-01	7.61E-01	3.25E-01	2.93E+00

Accidents with bunker oil spills

	Accident	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	2.23E-02	2.40E-03	1.43E-03	1.07E-03	3.21E-03	1.29E-03	1.29E-02
Struc	1.32E-02	1.42E-03	8.34E-04	6.56E-04	1.91E-03	7.59E-04	7.66E-03
FEX	1.16E-02	1.24E-03	7.30E-04	5.74E-04	1.67E-03	6.64E-04	6.70E-03
PGrd	5.72E-02	7.23E-03	4.32E-03	3.61E-03	1.25E-02	8.26E-03	2.13E-02
DGrd	4.05E-01	4.14E-02	2.69E-02	1.44E-02	5.68E-02	2.16E-02	2.44E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	2.74E-07	3.00E-08	3.40E-08	0.00E+00	1.00E-07	1.00E-08	1.00E-07
Total	5.09E-01	5.37E-02	3.42E-02	2.03E-02	7.61E-02	3.25E-02	2.93E-01

Bunkers oil spill volumes

	Risk	Area:	2	North			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	4.27E+00	5.39E-01	3.26E-01	1.30E+00	1.20E+00	1.46E-01	7.52E-01
Struc	2.61E+00	3.25E-01	1.90E-01	8.29E-01	7.31E-01	8.55E-02	4.48E-01
FEX	2.28E+00	2.84E-01	1.66E-01	7.25E-01	6.39E-01	7.47E-02	3.92E-01
PGrd	1.37E+01	1.77E+00	7.44E-01	4.52E+00	4.57E+00	7.46E-01	1.34E+00
DGrd	6.27E+01	8.45E+00	5.88E+00	1.32E+01	1.90E+01	2.30E+00	1.39E+01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	2.50E-05	2.00E-06	3.00E-06	0.00E+00	0.00E+00	0.00E+00	2.00E-05
Total	8.55E+01	1.14E+01	7.30E+00	2.05E+01	2.61E+01	3.35E+00	1.69E+01

Proposed route 2008

All accidents

	Total	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.82E-01	1.47E-02	1.01E-02	6.93E-03	2.76E-02	9.89E-03	1.13E-01
Struc	1.42E-01	1.57E-02	9.45E-03	6.55E-03	2.54E-02	8.99E-03	7.63E-02
FEX	1.24E-01	1.37E-02	8.26E-03	5.73E-03	2.22E-02	7.87E-03	6.67E-02
PGrd	5.52E-01	6.62E-02	4.04E-02	3.42E-02	1.18E-01	8.01E-02	2.13E-01
DGrd	3.42E+00	2.25E-01	1.56E-01	7.90E-02	3.66E-01	1.43E-01	2.45E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	2.47E-03	6.15E-04	1.69E-04	4.76E-04	1.01E-03	2.00E-04	2.92E-06
Total	4.42E+00	3.36E-01	2.24E-01	1.33E-01	5.61E-01	2.50E-01	2.92E+00

Accidents with bunker oil spills

	Accident	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.82E-02	1.47E-03	1.01E-03	6.93E-04	2.76E-03	9.90E-04	1.13E-02
Struc	1.42E-02	1.57E-03	9.45E-04	6.54E-04	2.54E-03	8.99E-04	7.63E-03
FEX	1.24E-02	1.37E-03	8.26E-04	5.73E-04	2.22E-03	7.86E-04	6.67E-03
PGrd	5.52E-02	6.63E-03	4.04E-03	3.42E-03	1.18E-02	8.02E-03	2.13E-02
DGrd	3.41E-01	2.25E-02	1.56E-02	7.90E-03	3.66E-02	1.44E-02	2.44E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	1.23E-04	3.07E-05	8.43E-06	2.38E-05	5.03E-05	1.01E-05	9.61E-08
Total	4.42E-01	3.35E-02	2.24E-02	1.33E-02	5.60E-02	2.51E-02	2.91E-01

Bunkers oil spill volumes

	Risk	Area:	2	North			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	3.68E+00	3.66E-01	2.33E-01	1.00E+00	1.27E+00	1.38E-01	6.75E-01
Struc	3.33E+00	3.92E-01	2.16E-01	8.79E-01	1.26E+00	1.30E-01	4.50E-01
FEX	2.91E+00	3.42E-01	1.89E-01	7.68E-01	1.11E+00	1.14E-01	3.93E-01
PGrd	1.32E+01	1.67E+00	6.73E-01	4.39E+00	4.37E+00	7.20E-01	1.34E+00
DGrd	4.35E+01	4.68E+00	3.42E+00	7.43E+00	1.24E+01	1.58E+00	1.40E+01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	1.83E-01	3.94E-03	7.30E-04	1.61E-02	1.56E-01	6.51E-03	1.94E-05
Total	6.68E+01	7.45E+00	4.73E+00	1.45E+01	2.06E+01	2.69E+00	1.68E+01

Today's route 2025

All accidents

	Total	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	3.81E-01	4.53E-02	9.27E-02	2.00E-02	5.00E-02	1.96E-02	1.53E-01
Struc	1.70E-01	2.06E-02	3.70E-02	9.45E-03	2.32E-02	9.19E-03	7.01E-02
FEX	1.48E-01	1.80E-02	3.24E-02	8.27E-03	2.03E-02	8.03E-03	6.12E-02
PGrd	7.00E-01	1.08E-01	9.72E-02	5.38E-02	1.49E-01	9.88E-02	1.93E-01
DGrd	5.10E+00	5.95E-01	1.11E+00	2.05E-01	6.88E-01	2.60E-01	2.24E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	8.10E-06	1.00E-06	2.10E-06	0.00E+00	2.00E-06	1.00E-06	2.00E-06
Total	6.49E+00	7.87E-01	1.37E+00	2.97E-01	9.31E-01	3.96E-01	2.72E+00

Accidents with bunker oil spills

	Accident	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	3.81E-02	4.53E-03	9.27E-03	2.00E-03	5.00E-03	1.96E-03	1.53E-02
Struc	1.69E-02	2.06E-03	3.70E-03	9.44E-04	2.32E-03	9.20E-04	7.00E-03
FEX	1.48E-02	1.80E-03	3.24E-03	8.27E-04	2.03E-03	8.04E-04	6.13E-03
PGrd	7.00E-02	1.08E-02	9.70E-03	5.38E-03	1.49E-02	9.89E-03	1.93E-02
DGrd	5.10E-01	5.95E-02	1.11E-01	2.05E-02	6.88E-02	2.60E-02	2.24E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	3.70E-07	4.00E-08	1.10E-07	0.00E+00	1.00E-07	2.00E-08	1.00E-07
Total	6.49E-01	7.87E-02	1.37E-01	2.97E-02	9.31E-02	3.96E-02	2.72E-01

Bunkers oil spill volumes

	Risk	Area:	2	North			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	8.85E+00	1.02E+00	2.39E+00	2.46E+00	1.87E+00	2.27E-01	8.95E-01
Struc	4.02E+00	4.70E-01	9.51E-01	1.20E+00	8.85E-01	1.03E-01	4.10E-01
FEX	3.51E+00	4.11E-01	8.31E-01	1.05E+00	7.74E-01	9.04E-02	3.59E-01
PGrd	1.88E+01	2.65E+00	1.80E+00	6.78E+00	5.47E+00	8.92E-01	1.21E+00
DGrd	9.81E+01	1.22E+01	2.86E+01	1.88E+01	2.30E+01	2.77E+00	1.28E+01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	4.30E-05	3.00E-06	1.00E-05	0.00E+00	0.00E+00	1.00E-05	2.00E-05
Total	1.33E+02	1.67E+01	3.46E+01	3.03E+01	3.20E+01	4.08E+00	1.56E+01

Proposed route 2025

All accidents

	Total	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	2.81E-01	2.70E-02	5.24E-02	2.10E-02	4.50E-02	1.50E-02	1.20E-01
Struc	1.88E-01	2.18E-02	4.04E-02	1.36E-02	3.17E-02	1.08E-02	6.97E-02
FEX	1.64E-01	1.90E-02	3.53E-02	1.19E-02	2.77E-02	9.41E-03	6.09E-02
PGrd	6.62E-01	9.93E-02	8.08E-02	5.13E-02	1.41E-01	9.58E-02	1.93E-01
DGrd	3.76E+00	3.19E-01	4.33E-01	1.42E-01	4.51E-01	1.73E-01	2.24E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	4.71E-03	9.22E-04	1.73E-03	7.15E-04	1.12E-03	2.24E-04	2.93E-06
Total	5.06E+00	4.87E-01	6.44E-01	2.40E-01	6.98E-01	3.04E-01	2.69E+00

Accidents with bunker oil spills

	Accident	frequency	Area:	2			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	2.81E-02	2.70E-03	5.24E-03	2.10E-03	4.50E-03	1.50E-03	1.20E-02
Struc	1.88E-02	2.18E-03	4.04E-03	1.36E-03	3.17E-03	1.08E-03	6.96E-03
FEX	1.64E-02	1.90E-03	3.53E-03	1.19E-03	2.77E-03	9.42E-04	6.10E-03
PGrd	6.62E-02	9.93E-03	8.06E-03	5.13E-03	1.41E-02	9.59E-03	1.93E-02
DGrd	3.76E-01	3.19E-02	4.33E-02	1.42E-02	4.51E-02	1.73E-02	2.24E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	2.36E-04	4.60E-05	8.64E-05	3.57E-05	5.62E-05	1.12E-05	1.97E-07
Total	5.06E-01	4.87E-02	6.43E-02	2.40E-02	6.97E-02	3.04E-02	2.69E-01

Bunkers oil spill volumes

	Risk	Area:	2	North			
	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	4.75E+00	4.07E-01	6.73E-01	2.00E+00	1.18E+00	1.14E-01	3.84E-01
Struc	2.92E+00	2.88E-01	5.14E-01	1.03E+00	7.98E-01	7.85E-02	2.11E-01
FEX	2.56E+00	2.52E-01	4.49E-01	9.05E-01	6.98E-01	6.86E-02	1.84E-01
PGrd	8.86E+00	1.25E+00	6.73E-01	3.29E+00	2.61E+00	4.30E-01	6.07E-01
DGrd	3.17E+01	3.38E+00	5.25E+00	7.81E+00	7.83E+00	9.59E-01	6.43E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	1.09E-01	2.95E-03	3.74E-03	1.20E-02	8.67E-02	3.63E-03	9.74E-06
Total	5.09E+01	5.57E+00	7.56E+00	1.50E+01	1.32E+01	1.65E+00	7.82E+00

Appendix 7: Calculation of confidence intervals

To calculate the reliability of the results, confidence intervals were estimated for the calculations of the accident frequencies and oil spill frequencies and their difference. Confidence intervals show the statistical uncertainties in numbers and risk figures. The calculations of statistical significance show whether or not risk differences between groups or periods are large enough to be considered real and not a result from random fluctuations. We have used the conventional significance level of 5%, which implies that the probability of the difference in risk figures being a result of random fluctuations is less than 0.05.

It is generally believed that the purely random variation in the accident rate complies with the so-called Poisson distribution. For large samples this is approximately equal to the normal distribution. The Poisson distribution is the standard deviation equal to square root of the century. A 95% confidence interval for an accident rate (n) is thus:

$$n \pm \left(1{,}96\sqrt{n}\right)$$

If the confidence interval for the two risk figures does not overlap, one concludes that the risk figures are significantly different. But also when the confidence intervals overlap, the two risk figures can be significantly different.

We use the formula below which takes into account the improbability of the two "true" risk numbers being in extreme of their confidence:

$$|D| \pm 1{,}96\sqrt{(s_1)^2 + (s_2)}^2$$

$|D|$ = Absolute value of difference between the risk figure 1 and risk figure 2

S_1 = standard deviation of the risk figure 1
S_2 = standard deviation of the risk figure 2

Reference:

Bjørnskau, T., *Risiko i trafikken 2005-2007.* TØI rapport 986/2008, 2008.

Appendix 8: Two case-scenarios. Report from Norconsult

The institute of transport economics (TØI)

Proposed ship's routing, TSS Utsira to TSS Risør

Comparative consequence analysis of representative ship accidents

October 27. 2009

Norconsult

D01	27.10.09	Final	JSA	ELLUN	GLE
A01	23.10.09	Review to client	JSA	ELLUN	GLE
Rev.	Date;	Description	Author	Verified	Approved

Client:

The institute of transport economics

Title:

Proposed ship's routing, TSS Utsira to TSS Risør

Comparative consequence analysis of representative ship accidents

Date; October 27. 2009

Issued by: Norconsult

Cotroller: JSA

Approved: GLE

Norconsult	Project number	Document number:	Rev.
	5013627	102	A01

Content

1 REPRESENTATIVE SCENARIOS

1.1 Method

In the real world the variety of incidents and accidents involving ships is infinite. Statistical models provide quantitative probability (frequency) of incidents of a certain category, timeframe and area. However, the probability of a specific scenario (date, cause, location, release volume, pollutant characteristics, weather, current, sea state etc.) can not be calculated based on today's model and data. Hence a simplified approach is needed.

To demonstrate how the proposed ship's routing alters risk, we use a generic and comparative approach:

- Probability of collision (and other types of incidents) is calculated for TSS Utsira to TSS Risør, and for today's ship's routing in the same area.

  NOTE: Not all collisions cause release of pollutant. However, the relative change of probability (frequency) for collisions is regarded as a strong indicator for comparing today's traffic routing and the proposed new routing.

- Representative (typical) scenarios are then defined based on type of traffic, existing and future routing, type of cargo, typical weather etc.
- Each scenario is then positioned at two locations: (A) A high density traffic location where this type of ship is sailing today (based on AIS data), and (B) the expected position of the collision if that same ship had used the new routing. All positions were validated by the NCA.
- The sequence of events for that scenario located at two different positions is then simulated.
- A relative comparison of consequences between A and B is then performed.

To ensure comparable results, the scenario at location A and B are identical. All assessments are conducted using identical simulation tool, input data and assessment methodology. This methodology ensures that we can identify:

- Change of probability per year for todays and future routing for a given category of incident.
- Consequence differences between A and B locations for each scenario.

Although risk (probability x consequence) is not calculated, this methodology enables identification of relative change of both probability and consequence independently.

To assess environmental consequences for each scenario we have chosen to use the relative difference of impact areas as the main parameter. This is due to the fact that the actual oil spill concentration and distribution within the archipelago is highly dependent on a wide range parameters not part of today's model tools.

MOB (Miljø Og Beredskap) is the national regime for the prioritisation of environmental resources during oil spills emergency response in Norwegian waters. The prioritising is made up by a system of parameters e.g. oil pollution vulnerability, conservation value, the resource's natural occurrence as well as whether the environmental loss can be compensated economically or not. These parameters form the basis for the priority category, which range from A-D; with A being the highest level of priority. The prioritizing work has been conducted by the local environmental authority.

Our quantification is performed by summarising the MOB areas of different categories within the scenario impact areas. The data used for these scenarios are based upon the data from *Kystinfo*, the public GIS tool of the Norwegian Coastal Administration. The MOB-data in this tool was updated October 9. 2009. The data used for quantification of fish spawning areas is based upon the same tool but from the website of The Norwegian Directorate of Fisheries.

1.2 Acute oil pollution - emergency response

The Pollution Control Act states that the National Contingency System is divided into private, municipal and governmental contingency areas with specific responsibilities. In Norway, all contingency plans and organizations are standardized and co-ordinated. Hence, in the event of a major acute pollution incident, the national contingency system under the supervision of The Norwegian Coastal Administration (NCA) will work as a single integrated response organisation.

NCA is a directorate of the Ministry of Fisheries and Coastal Affairs responsible for sea transport, maritime safety, ports and emergency response to acute pollution. Large-scale incidents of acute pollution mainly relates to oil spills from ships, off-shore installations, shipwrecks or from unidentified sources. NCA has its own surveillance aircraft, 16 oil-spill depots and 9 intermediate depots with oil-spill recovery equipment. The Administration has also equipment stationed on board a number of vessels, including the Norwegian Coast Guard's vessels as well as the Administration's own vessels. As part of the national emergency response system an oil drift model service is provided by the Norwegian meteorological Institute, Marine Forecasting Centre (DNMI). Based on sophisticated ocean and weather models, the end user such as NCA and major private contingency organisations can access this tool through a web interface (Kilden). NCA has provided the oil drift simulations to this report.

1.3 National emergency tow system

NCAs national emergency tow system constitutes the following resources from TSS Røst to TSS Risør:

Location of emergeny tows

Location	North	East	Number	Bollard pull (te)	Length	Speed
Oslo/Brevik	59°22`	9°41`	1	35	29,4	10
			2	29	26,2	N/A
			3	35	29,4	13
			4	25	N/A	N/A
			5	35	26,7	12
Kristiansand	58°08`	7°59`	1	22	25,2	N/A
Farsund	58°03`	6°44`	1	24	N/A	N/A
Kårstø	59°17`	5°31`	1	50	30,8	13
			2	42	29,7	12
			3	42	29,7	12
Slagentange	59°19`	10°31`	1	53	32,9	14,5
Sture	60°38`	4°49`	1	53	33,3	12
			2	65	37	15
			3	92	41,6	15
Stavanger	58°57`	5°43`	1	35	N/A	N/A
			2	43	30,26	12,5
			3	62	35	14,5
			4	90	45,5	14,5
Bergen	60°23`	5°19`	1	64	N/A	N/A
Mongstad	60°48`	5°02`	1	95	40,55	15
			2	67	38,85	15,5
			3	65	35	13
			4	53	36	N/A
Kristiansund	63°07`	7°41`	1	26	N/A	N/A
			2	26	N/A	N/A
Trondheim	63°26`	10°23`	1	39	N/A	N/A
			2	20	N/A	N/A
Ålesund	62°28`	6°05`	1	31	N/A	N/A
			2	20	N/A	N/A
			3	35	N/A	N/A
Sandnessjøe	66°01`	12°36`	1	50	N/A	N/A
Narvik	68°23`	17°41`	1	23	N/A	N/A
				47	N/A	N/A
				43	N/A	N/A

1.4 Scenarios - environmental impact areas

The scenarios were selected based on the following criteria:

- The national dimensioning oil spill scenarios defined by the Ministry of fisheries and coastal affairs (20 000 m^3 crude, 1000 m^3 & 5000 m^3 fuel oil)
- AIS data and the identification of high density traffic "hot spots" (elevated collision risk)
- Potential threat to coastline and vulnerable marine resources
- Typical wind and sea current, and inside operational window for oil spill response

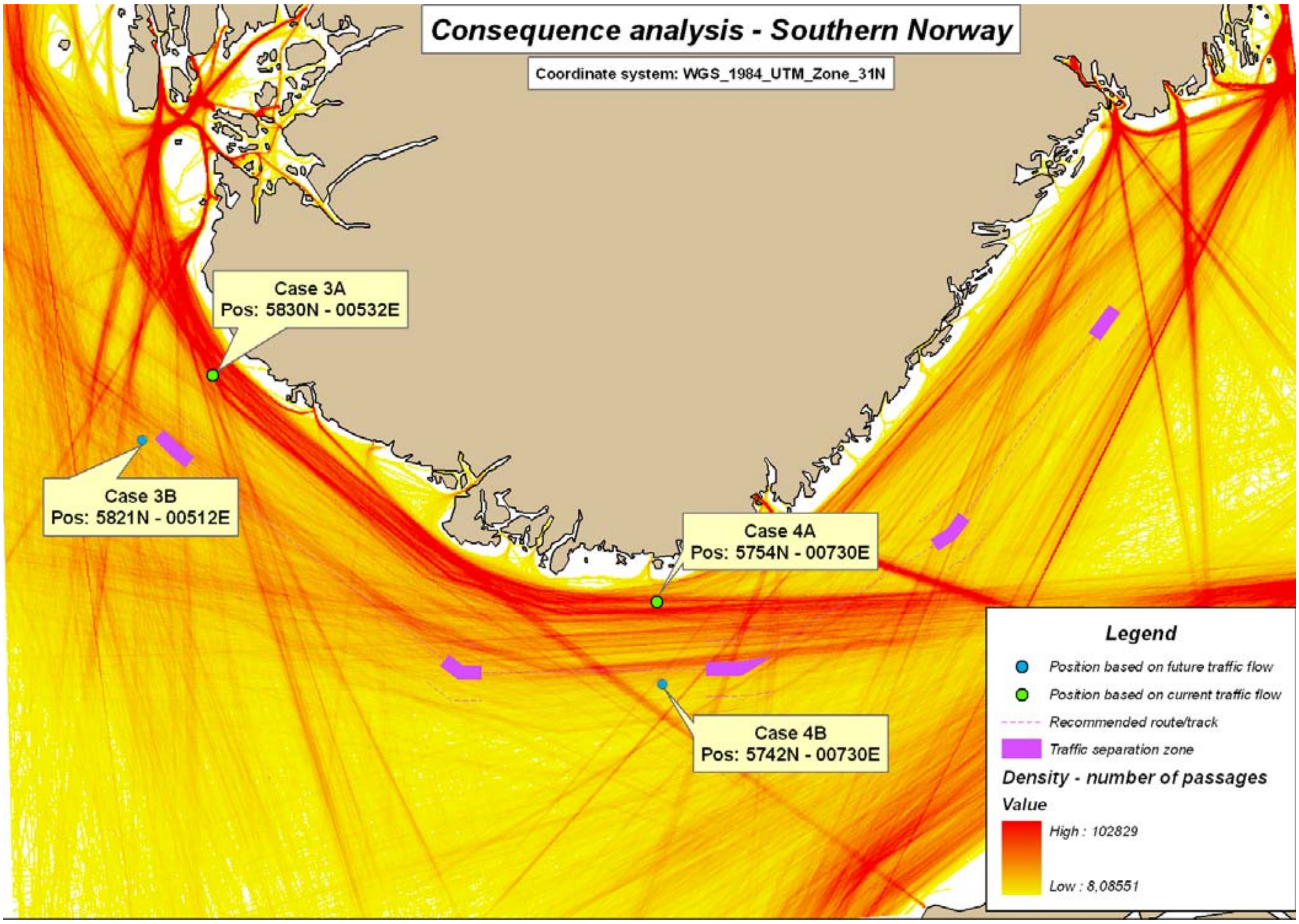


Figure 1.4A: AIS data from 2008, green circle show locations of scenarios in this report

Concerning environmental impact, the national Marine Resources DataBase (MRDB) has been developed by DNV with funding from authorities and private industry. Chapter 2.2 explains this data in more detail.

1.4.1 Scenario 3A and B, bunker oil release south of Stavanger

Scenario 3A and 3B are identical except from location:

- Location A: N58^{0}30', E005^{0}32' - a high density traffic spot based on AIS data
- Location B: N58^{0}21', E005^{0}12' - closest point to (A) given new routing, south bound

Key data concerning the scenario:

- Type of incident: Collision, ore carrier
- Time of year: Spring
- Release type: Sea surface release
- Oil type: Bunkers, IFO260 (intermediate fuel oil)

- Release volume: 1000 m^3 during 4 hours
- Weather: Wind 10 m/s from 200 deg, 0,15 km sea current along coastline towards north-west (Represents 15% of all wind direction measurements, 5 % of wind speed measurements)

Simulation of initial shoreline impact

By using the DNMI oil drift simulation model, the initial shoreline impact length as well as the oil mass balance (evaporation, dispersion, on surface) has been calculated by NCA. Please note that the figures in this chapter are showing one dataset (time-step) only for comparison. Hour-by-hour simulation data has been utilized to obtain the results. The model is unable to simulate secondary oil spill impact that is re-migration of oil that already has reached the shoreline. However, qualitative data based on extensive experience from recent oil spill response operations is used in chapter 2 to assess the long-term shoreline impact

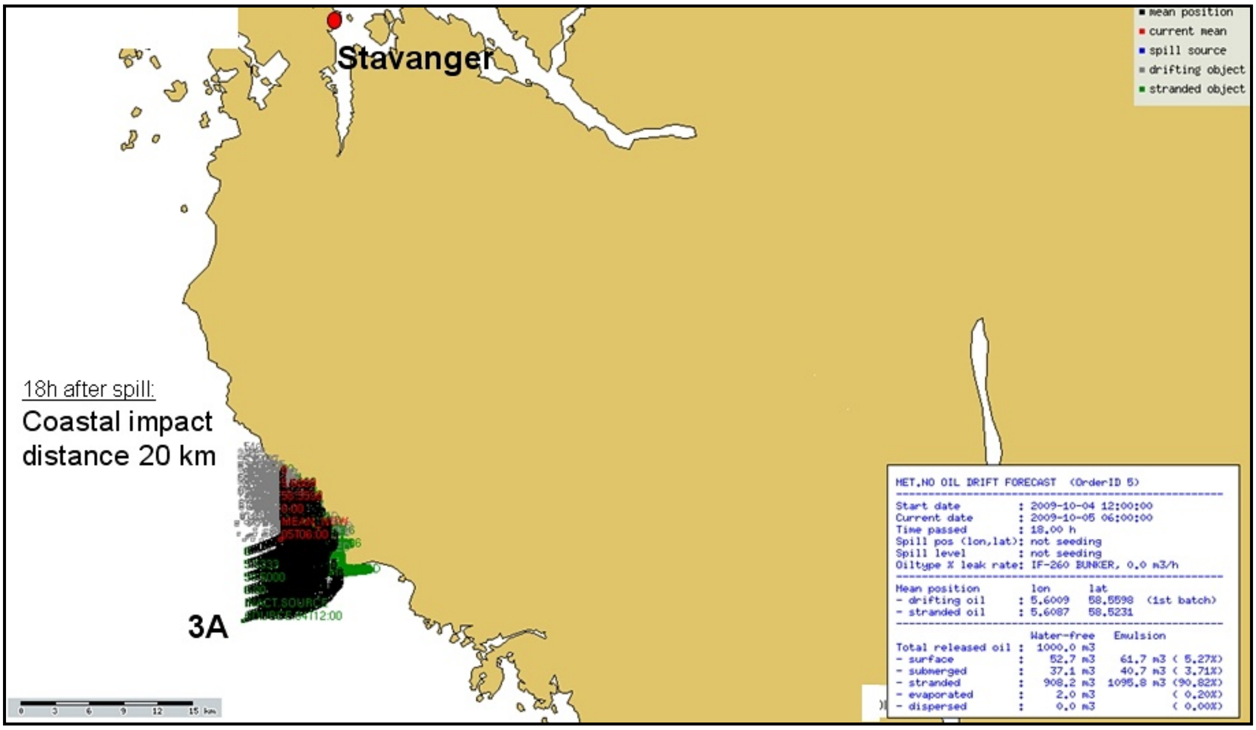


Fig 1.4.1A: Surface release from position 3A, situation after 18h (Courtesy of NCA/DNMI)

Simulation results, scenario 3A

- Time from release to shoreline impact: 10 h
- Initial shoreline impact length: 20 km
- Oil volume reaching shoreline, first batch: 998 m^3

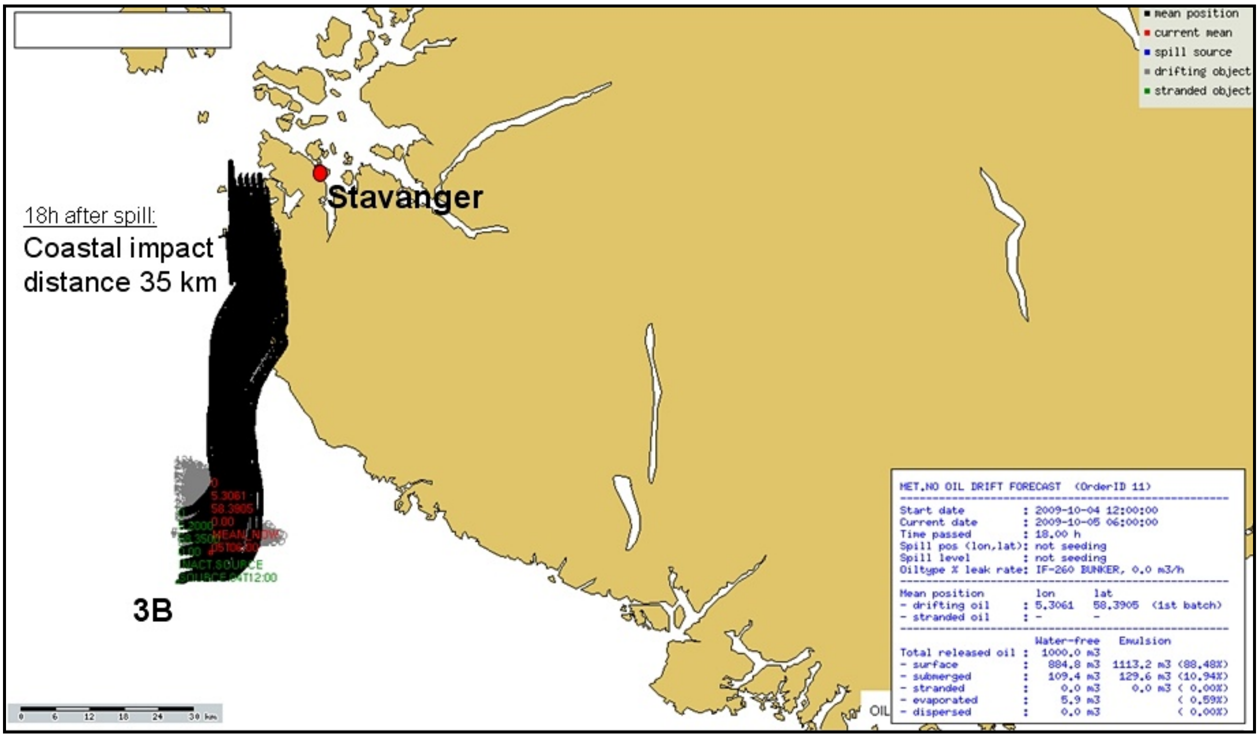


Fig 1.4.1B: Surface release from position 3B (new routing) situation after 18h (Courtesy of NCA/DNMI)

Simulation results, scenario 3B

- Time from release to shoreline impact: 70 h
- Initial shoreline impact length: 35 km
- Oil volume reaching shoreline 780 m^3

1.4.2 Scenario 4A and B, crude oil release south of Lindesnes

Scenario 4A and 4B are identical except from location:

- Location A: N57^{0}54', E007^{0}30' - a high density traffic spot based on AIS data
- Location B: N57^{0}42', E007^{0}30' - closest point to (A) given new routing, east bound

Key data concerning the scenario:

- Type of incident: Collision
- Time of year: Autumn
- Release type: Release from sea bed (A: -183m, B: -349 m)
- Oil type: Light crude oil (Draugen)
- Release volume: 20 000 m^3 during 24 hours
- Weather: Wind 15 m/s from 150 deg, 0,15 km sea current along coastline towards south-west (Represents 4% of all wind direction measurements, 15 % of wind speed measurements)

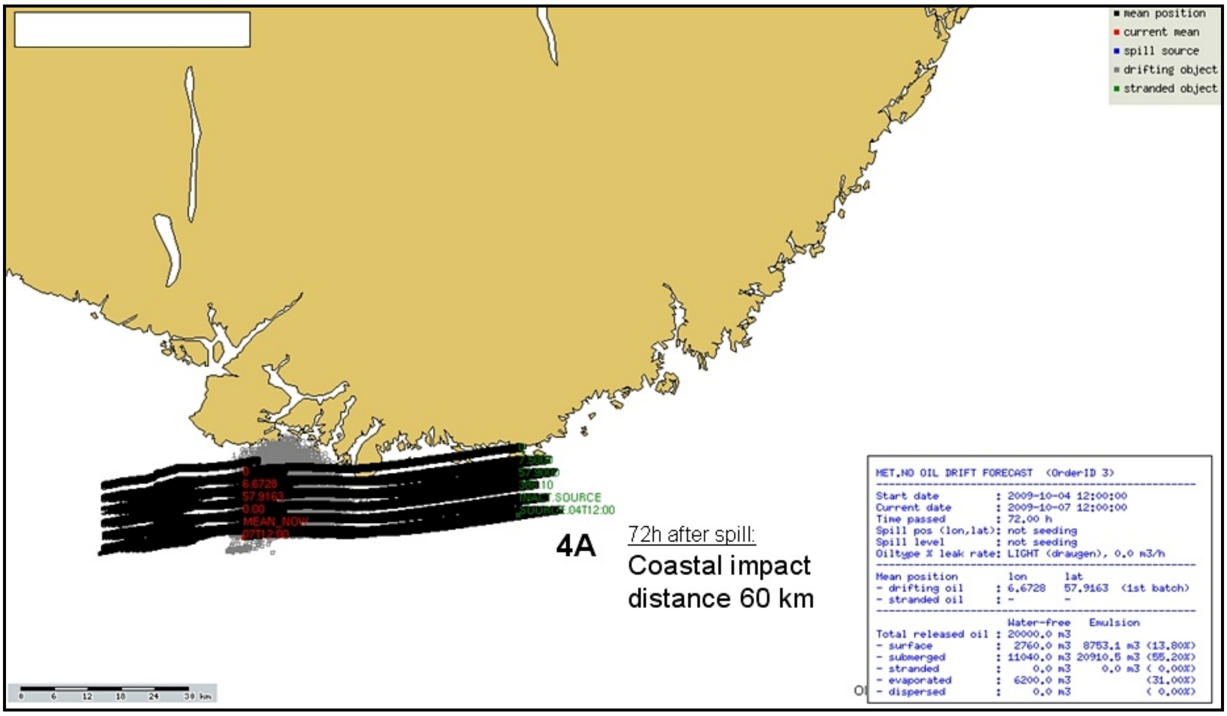


Fig 1.4.2A: Subsea release from position 4A situation after 72h (Courtesy of NCA/DNMI)

<u>Simulation results, scenario 4A</u>

- Time from release to shoreline impact: 12 h
- Initial shoreline impact length: 60 km
- Oil volume reaching shoreline, first batch: 9 000 m^3

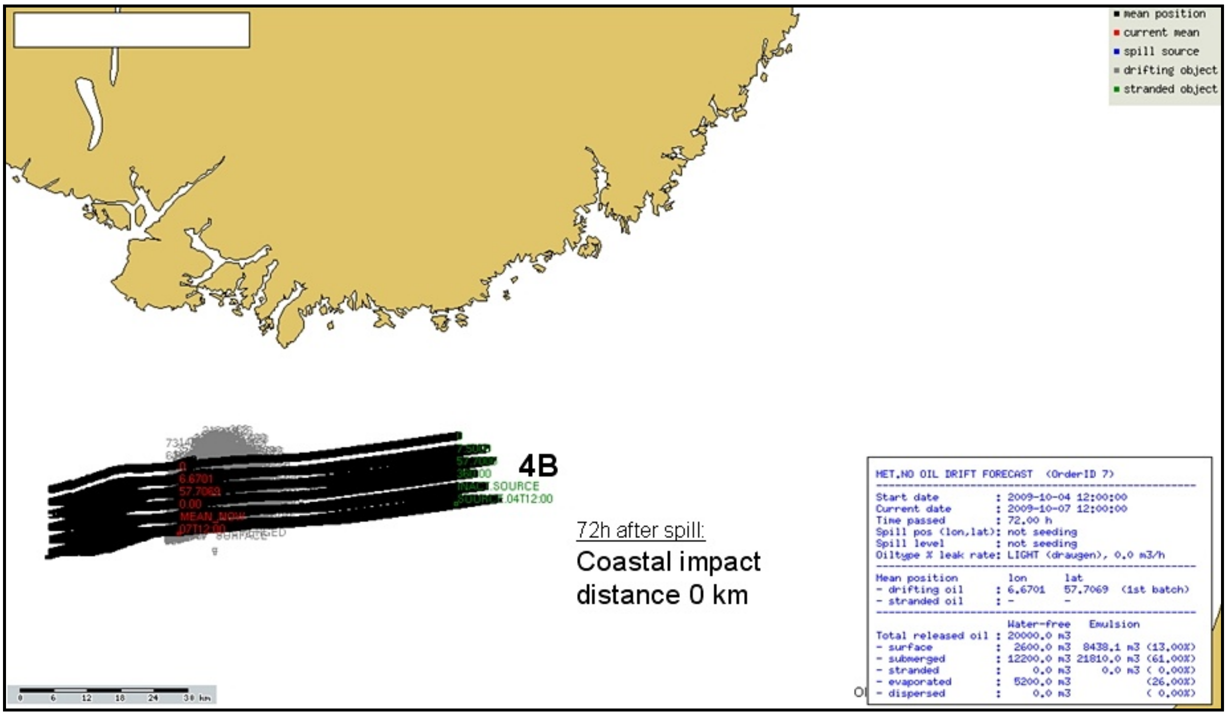


Fig 1.4.2B: Subsea release from position 4B (new routing) situation after 72h (Courtesy of NCA/DNMI)

Simulation results, scenario 4B

- Time from release to shoreline impact: No shoreline impact
- Initial shoreline impact length: 0 km
- Oil volume reaching shoreline, first batch: 0 m^3

After 120 hours in the prevailing wind conditions and temperatures, this oil will be natural degraded (evapuration, dispersion) within 5-6 days.

1.5 Scenarios - ship grounding and emergency towing

To assess the potential for emergency towing preventing ship grounding (and spill), time from propulsion failure (at position A and B for each scenario) until grounding has been calculated and compared with tug boat response times.

In the document "Nasjonal slepeberedskap" (National emergency tug preparedness) issued by the Norwegian Coastal Administration (2006) thousands of ship drift simulations were conducted by DNV using the SHIPDRIFT model. It shows that drifting speed for large vessels varies between 1.2 to almost 4 knots, depending on ship dimensions, wind and ocean current. For this comparative analysis, we use shortest drifting distance and 2.5 knot (wind above 10 m/s) and 2.0 knot (wind below 10 m/s) drift speed.

1.5.1 Scenario 3A and B, ship drifting towards shore south of Stavanger

For scenario 3A and B, the following tug boat availability exists, given that the tug boats are in port when request for assistance is received:

- Location: Stavanger
- Tug boat speed: 14.5 kn (several boats are available)
- Distance to location 3A: 74 km
- Distance to location 3B: 92 km
- Response time to location 3A: 2.7 h
- Response time to location 3B: 3.4 h

Given propulsion stop at location A and B, the minimum drifting times to grounding are:

- Distance from location 3A to nearest shoreline: 10 km
- Distance from location 3B to nearest shoreline: 35 km
- Time from loss of propulsion to grounding, location 3A: 2.1 h
- Time from loss of propulsion to grounding, location 3B: 7.6 h
- Tug boat arrive in time, location 3A?: No
- Tug boat arrive in time, location 3B?: Yes

1.5.2 *Scenario 4A and B, ship drifting towards shore south of Lindesnes*

For scenario 4A and B, the following tug boat availability exists, given that the tug boats are in port when request for assistance is received:

- Location: Farsund
- Tug boat speed: 12 kn (data unavailable, conservative speed)
- Distance to location 4A: 52 km
- Distance to location 4B: 60 km
- Response time to location 4A: 2.3 h
- Response time to location 4B: 2.7 h

- Location: Kristiansand S
- Tug boat speed: 12 kn (data unavailable, conservative speed)
- Distance to location 4A: 44 km
- Distance to location 4B: 61 km
- Response time to location 4A: 2.0 h
- Response time to location 4B: 2.7 h

Given propulsion stop at location A and B, the minimum drifting times to grounding are:

- Distance from location 4A to nearest shoreline: 8.9 km
- Distance from location 4B to nearest shoreline: 30 km
- Time from loss of propulsion to grounding, location 4A: 1.9 h
- Time from loss of propulsion to grounding, location 4B: 6.4h
- Tug boat arrive in time, location 4A?: No
- Tug boat arrive in time, location 4B?: Yes

2 ENVIRONMENTAL CONSEQUENCES

2.1 Oil spill emergency response effectiveness and cost

The oil spill response may reduce the volume of oil reaching the coast. The efficiency of open ocean oil spill response is highly dependant on prevailing weather and coastal currents. In Norway, there are 16 governmental oil spill response depots, and off-shore oil spill response equipment (booms and skimmers) are located on board Royal Norwegian Coastguard vessels patrolling the coastline. The depots are dependant on use of vessels of opportunity.

In the vicinity of scenario 3A, an oil spill response depots are located in Stavanger. Closest depot to scenario 4B is Kristiansand.

- One coastguard vessel will be first on site, 4 hours after accident. The 2nd after 12 hours.
- One oil spill response system will be on site after 5h (preparations) + time to reach site.
- For each additional 24 hours, number of response systems will double until the 3rd day.
- Crude oil recovery rate is 50 m^3 oil per. hour for coastguard system below 10 m/s wind
  25 m^3 oil per. hour for each coastguard system above 10 m/s and for all depot based systems
- Fuel oil recovery rate is 10 m^3 oil per. hour for coastguard system below 10 m/s
  5 m^3 oil per. hour for each coastguard system above 10 m/s depot based systems
- Max possible off-shore oil spill recovery: 75 % (due to unrecoverable films, patchy structure etc)
- Clean-up cost per m^3 crude oil NOK 200 000, heavy fuel NOK 500 000
- Natural degradation vs. manual clean-up of oil reaching shore: 60 % / 40 %.

The effect of oil spill response is related to volume only (volume of oil pr. km^2), not on impact area. For crude oil, actual recovered fluid volume will be doubled due to emulsification, hence the low rates related to non-emulsified oil (we have used the "20 % of skimmer capacity" rule of thumb, used in North America)

Scenario 3A

Oil spill recovery

Time from incident to shoreline impact for 3A is 10 hours. During this timeframe the following oil spill response systems will be in action:

- One coastguard vessel, 10 - 4 = 6 hours of operation. Recovery: 6 x 5 m^3 = 30 m^3
- One system from Stavanger depot: 10-5-2 = 3 hours of operation: Rec: 3 x 5 m^3 = 15 m^3

The oil budget for shoreline impact is: 998 (from model) - 30 - 15 = 953 m^3

Clean up cost

- 40% of 953 m^3 equals 381 x 500 000 NOK = 190 mill. NOK

Scenario3B

Oil spill recovery

Time from incident to shoreline impact for 3B is 70 hours. During this timeframe the following oil spill response systems will be in action:

First 24 hours:

- One coastguard vessel, 24 - 4 = 20 hours of operation. Recovery: 20 x 5 m^3 = 100 m^3
- 2nd coastguard vessel, 24 - 12 = 12 hours of operation. Recovery: 12 x 5 m^3 = 60 m^3
- One system from Stavanger depot: 24-5-3 =16 hours of operation: Rec: 16 x 5 m^3 = 80 m^3
- Total, first 24 hours: 240 m^3

Doubling of capacity every 24 hours: 240 + 480 + 960 = 1680 after 72 hours, more than the initial release. Hence the 75% rule of thumb will be effective.

The oil budget for shoreline impact is: 25% of 998 m^3 = 250 m^3

Clean up cost

- 40% of 250 m^3 equals 100 m^3 x 500 000 NOK = 50 mill. NOK

Scenario 4A

Oil spill recovery

Time from incident to shoreline impact for 4A is 12 hours. During this timeframe the following oil spill response systems will be in action:

- One coastguard vessel, 12 - 4 = 8 hours of operation. Recovery: 8 x 25 m^3 = 200 m^3
- One system from Kristiansand depot: 12-5-2 = 5 hours of operation: Rec: 5 x 25 m^3 = 125 m^3

The oil budget for shoreline impact is: 9000 (from model) - 200 - 125 = 8675 m^3

Clean up cost

- 40% of 8675 m^3 equals 3470 x 100 000 NOK = 347 mill. NOK

Scenario4B

Oil spill recovery

Time from incident to shoreline impact for 1B is infinite - no shoreline impact.

Clean up cost

- No clean-up cost from shorelines.
  10 ships for 10 days, rate 150 000 NOK per day: 15 mill. NOK

2.2 Environmental impact of oil spills

The actual coastal impact area is dependant on re-migrating of oil from shorelines, weather, effectiveness of the oil spill response and the topography of the archipelago and fjord systems. In general, the initial impact area expands as distance between the spill and shoreline increases, given wind/current towards land. This is valid to a point where no oil reaches the shoreline due to evaporation and natural degradation.

The oil drift simulation model used in chapter 1 is unable to calculate re-migration of oil after initial shoreline impact. Therefore, a qualitative assessment of the impact area is made based on experiences from previous oil spills in Norway. The situation maps in this chapter show the potential impact area one week after release. For most vulnerable environmental resources, the concentration of oil is not strongly correlated with actual environmental damage. This is due to the fact that oil is not even distributed, but concentrated in bays and areas of certain coastal currents. Usually, environmental damage is the same given 2 cm or 4 cm of oil is on its surface. Therefore, in this generic and simplified comparison, we do not use oil quantity per. square kilometre, as this is a weak indicator of actual environmental impact.

The marine environment and its inhabitants are threatened by many factors. Utilization, habitat destruction and climate changes are just some of them. An oil spill incident may harm populations or ecosystems in different ways and to different degrees according to the environmental pressure this area or population are already experiencing. The toxic components of oil, the polycyclic aromatic hydrocarbons may cause physical, physiological or behavioural damages to the flora and fauna affected. This may lead to lethal or sub lethal effects.

An environment or population that are decimated by oil spill may recover after a number of years. If decimated twice or more times this may be more severe. This is the case for some parts of the western coast of Norway were the frequency of passing ships is high and the coastal environment and weather conditions are harsh. The possibility of accidents may therefore be relatively high. It is therefore of high importance to take measures to reduce the number of oil spills along Norway's vulnerable coastline.

Severe injuries to the marine environment have been seen worldwide, and one of the most infamous is the Exxon Valdez grounding in Prince William Sound, Alaska, April 1989. A total of 40 000 m^3 of crude oil was released into the sea. The oil eventually covered 28,000,000 km^2 of the coastal zone. Thousands of animals died immediately; estimates range from 250,000 to as many as 500,000 seabirds, at least 1,000 sea otters, approximately 12 river otters, 300 harbor seals, 250 bald eagles, and 22 orcas, as well as the destruction of billions of salmon and herring eggs. The consequences are still present and overall reductions in population have been seen in various marine animals, including stunted growth in pink salmon populations. The shoreline may need 30 years or more to fully recover.

In Norway there have been several mid-size incidents causing extensive oil spills during the last decade. One example is the "MS Server" grounding north-west of Bergen in January 2007. It is estimated that the spill killed between 3200-8000 seabirds. This incident alone may not cause long term effects, but the fact that the seabird populations in this area did experience a similar accident only three years earlier (the "MS Rocknes" grounding) may increase the total environmental effect.

Investigations of marine flora and fauna in the months after the "MS Server" accident showed a clear reduction in the density of certain seaweed species (*Pelvietia canaliculata).* The abundance of sessile fauna, filter feeders and snail species that are feeding on seaweed were clearly reduced in the affected areas. Similar reductions in flora and fauna were also reported after the oil spill following the accident of "Mercantil Marica" in Solund municipality in 1989.

Fish and invertebrates - oilspill vulnerability

Fish and invertebrates are vulnerable to oil spills. Due to the nature of oil, were it is transported and spread on the surface before it hits the shore; the bottom living animals in the open sea are less vulnerable than pelagic living, but in the coastal area both pelagic and bottom living may be affected. They are mostly exposed to water soluble components as their main source of contact would be through respiration from water through their gills. Dispersed oil components my also be taken up through the mouth or through prey organisms that have themselves taken up oil components. This may lead to accumulation of toxic components in the predator. Both invertebrates and fishes are most sensitive to toxic response in their larval stages, just after hatching and through the digestion of the yolk sack.

Physiological effects: reduced heart frequency, changes in the salinity balance and change in blood parameters; blood cells, hormone levels etc. There has also been observed problems for reproduction including increased infertility, reduced egg production and reduced survival for the offspring.

Behavioural effects: Changes in hunting and reproductive behaviour have been observed along with reduced anti predator behaviour like crabs that has been observed to change its normal behaviour for avoiding predators by digging itself down in the sediment.

Morphological effects: has been observed adult stages were damages to gills, intestine, pancreas, spinal cord and brain damages.

Fish can smell oil and if possible they may avoid areas of oil spill. Zooplankton has been shown to recover rather fast after an oil spill due to their short generation time. Benthos may be exposed to the toxic components for longer time due to storage and leaking of oil components in the bottom sediment.

Oil polluted rocks and shores will also be a barrier for new recruitments of sessile organisms. Reduction of sessile organisms and filter feeders were also observed after the MS Server incident. It has been shown that amphipods and decapods are relatively more sensitive to oil spills than isopods that generally are more resistant. Fish and crabs caught in the sea after the accidents and oil spill from MS Server outside Fedje in Hordaland, Norway, contained 20 times more PAH than the background concentrations.

Seabirds - oil spill vulnerability

Seabirds are probably one of the most vulnerable animal groups to oil spills. Oil polluted birds are often the most prominent picture from a spill incident, but studies also conclude that oil spills have contributed to decreased populations of seabird species. This has not yet been shown for other animal groups.

As for other some mammals, the external pollution is the most acute. Oil in the feathers results in clogging and reduction of the water resistance, and it prevents the insulation ability of the feathers and reduces the ability for heat regulation. If exposed to water, the animal may freeze to death. If the bird reaches land it can probably escape the freezing, but it may have problems finding appropriate food. This may lead to starvation. Birds have also been observed efficiently cleaning their own feathers, but this may lead to digestion of heavy amounts of oil causing anaemia, disturbed osmoregulation, hormonal effects and reproductive effects as well as reduced and delayed lying of eggs and reduced thickness of the egg shell.

As for other animal groups the embryonic stages and juveniles are most sensitive. Just small amounts of oil may cause genetic and morphological injuries to the embryo, delay the embryonic development and increase the post hatching mortality. For the young birds the salinity balance may be disturbed, reduced intestine absorption and liver injuries may occur. This leads to reduced growth and increased mortality.

During moulting, seabirds gather in the open waters and they may be unable to fly for a period of up to two months. In this period they will be very vulnerable to external stress and pollution. Indirect consequences for seabirds may also be that prey organisms may disappear from a polluted area and this will again decrease their survival.

Mammals - oil spill vulnerability

Sea living mammals may be affected by oil spills in different ways. They should be able to swim out of an area, and whales have in experiments learned to avoid areas of oil spills after first encounter with the spill.

However, common seals have shown the opposite behaviour during the Exxon Valdez accident, rather seemed to be attracted by the spill.

Adult animals are protected from external contamination by their thick skin, but the infants may be vulnerable, especially just after birth. For whales, heavy oil may cause temporarily reduction in the water flow through the baleens, but this is not seen to cause any severe effect for the animal. However, whales and seals may be affected by inhalation of hydrocarbons that can lead to death due to high levels of adrenalin and hydrocarbons in the blood, and due to its narcotic effect that can lead to instant drowning. Also digestion of contaminated prey can cause liver injuries and negatively affect reproduction. The mortality of killer whales after the Exxon Valdez incident increased 5-6 times during the following two years, especially affecting young and female animals.

Sea otters are dependent on their fur for thermal insulation and the first effect of oil pollution will be clogging of the fur when externally exposed to oil. This will reduce the animal's ability for heat regulation and it may stay on lad for longer periods. On land it can not find food and will starve. It will also try to clean its fur, and this activity may reduce the time spent for hunting for food. Also this behaviour may cause the animal to digest a lot of the oil from the fur causing internal damages for the digestion system. Also stress, shock and respiratory effects have been observed.

Scenario 3A and B

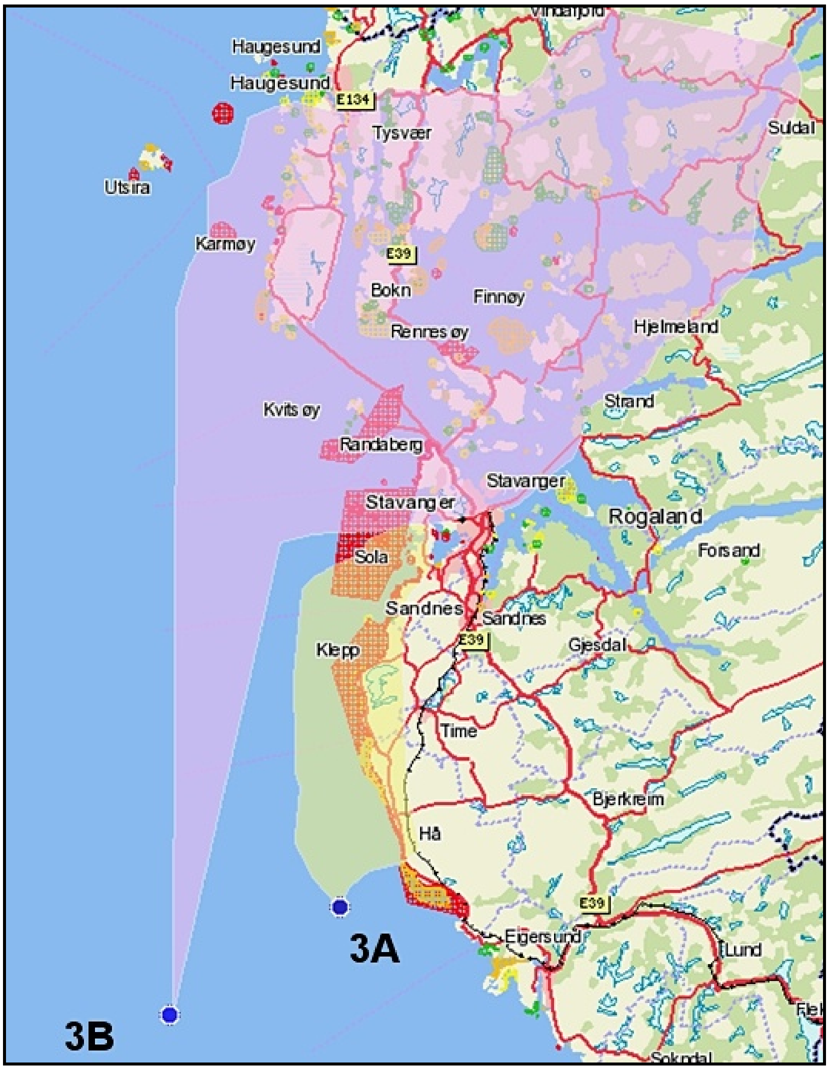


Figure 2.2A: Impact areas of 3A and 3B after 1 week based on experiences from past spills

Vulnerable environmental resources within the two areas:

No. of MOB areas (m^2)	3A	3B	Increase A>B
Mob A Summer	6	20	233 %
Mob A Winter	6	18	200 %
Mob B Summer	3	30	900 %
Mob B Winter	0	11	
Mob C Summer	3	33	1000 %
Mob C Winter	3	52	1633 %
Mob D Summer	0	15	
Mob D Winter	1	92	9100 %
No. of protected areas	0	0	
Spawning areas	10	21	110 %

Size of MOB-areas (m^2)	3A	3B	Increase A>B
Mob A Summer	2,01E+08	2,51E+08	25 %
Mob A Winter	2,01E+08	2,51E+08	25 %
Mob B Summer	19332017	44531617	130 %
Mob B Winter		16391002	
Mob C Summer	5552327	38670103	596 %
Mob C Winter	5552327	70854365	1176 %
Mob D Summer		13886837	
Mob D Winter	781411,5	81811954	10370 %

Most of the MOB areas that may be affected by an oil spill in this region are seabird habitats where birds breed and feed. Some also use these sites for resting on their way southwards in the autumn and others will spend the winter here. There is a wide range of different seabird species and some are diving for food while others are surface feeders. All these strategies may make the birds vulnerable for injuries and subjected to prey deficiency in case of an oil spill that covers big parts of their target area.

The area is also home to marine mammals. An incident happening in the spring that coincides with hatching and birth may cause severe injuries and increase the mortality for this offspring. Scenario A will affect only a limited amount of recreational areas while the B scenario will affect more areas of this category. There are registered observations of deep water corals (*Lophelia pertusa)* in the area affected by scenario B. This specie is red listed but live below 40 m depth, and will therefore not be directly exposed.

Scenario A covers 10 registered spawning areas, 9 for cod and one for shrimp from January (shrimp:Feb) to April. Scenario B covers almost double the amount of areas and also includes spawning areas for herring, blue whiting, haddock, pollack and horse mackerel. An oil spill incident occurring during the spring may severely effect the survival of fish larvae, especially for pelagic spawning species. Cod, pollack, haddock, horse mackerel and blue whiting all belong in this category, but in deep waters, from 100 m and deeper. This behaviour may limit the risk for being affected by an oil spill in the early stages. However, shrimps are bottom living but migrate vertically through the water column during the night.

Scenario 4A and B

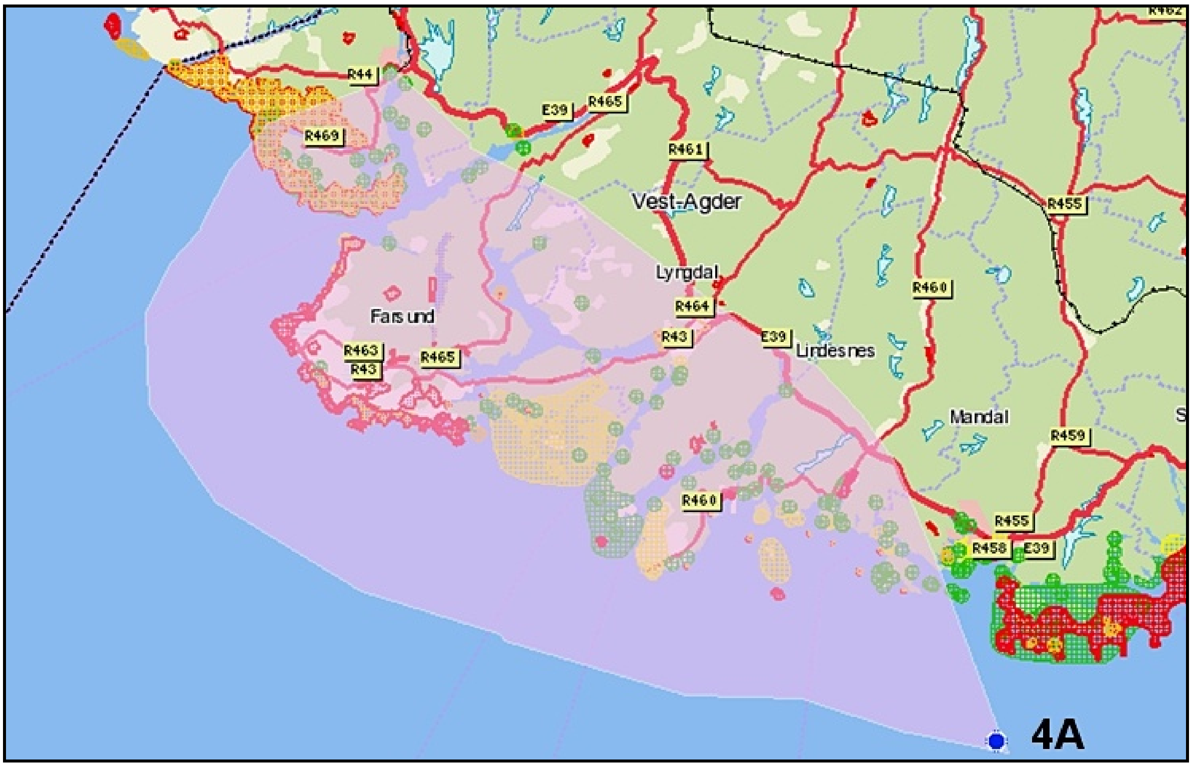


Figure 2.2B: Impact areas of 4A after 1 week based on experiences from past spills

The spill from location 4B did not reach land due to the dominating coastal current

Vulnerable environmental resources within the two areas:

No. of MOB areas (m^2)	4A	4B
Mob A Summer	12	Not relev.
Mob A Winter	8	Not relev.
Mob B Summer	17	Not relev.
Mob B Winter	1	Not relev.
Mob C Summer	30	Not relev.
Mob C Winter	29	Not relev.
Mob D Summer	78	Not relev.
Mob D Winter	93	Not relev.
No. of protected areas	1	Not relev.
Spawning areas		

Size of MOB-areas (m^2)	4A	4B
Mob A Summer	12382243	Not relev.
Mob A Winter	8560496	Not relev.
Mob B Summer	59012782	Not relev.
Mob B Winter	781413	Not relev.
Mob C Summer	95091027	Not relev.
Mob C Winter	1,44E+08	Not relev.
Mob D Summer	60950214	Not relev.
Mob D Winter	96210878	Not relev.

In this scenario, only a spill occurring along the old route seems to reach the shore. In scenario B the oil will be taken by the strong coastal current into the North Sea. How this will affect the environment here is uncertain but the time of the scenario, autumn, will not affect the breeding and hatching season for fishes and thereby has limited effect for the coming generations. Many seabird species, e.g. kittiwake, common guillemot and razor-billed auk are very common in the North Sea during autumn and winter time. The duration of exposure of oil spill in scenario 4B the on the surface, available for swimming birds, is estimated to 5 days. As the time of this scenario does not coincide with moulting the birds may avoid the spill by flying away.

Most of the MOB areas that may be affected on the shore by an oil spill in this region are seabird habitats where the birds breed and feed. Some also use these sites for resting on their way southwards in the autumn and others will spend the winter here. There is a wide range of different seabird species here were some are diving for food and others are surface feeders. All these strategies may make the birds vulnerable for injuries and subjected to prey deficiency in case of an oil spill that covers big parts of their target area. It may also affect more birds do to accumulation of birds for resting and spending the winter here. However, incidents happening in the autumn may not affect the local bird population on a large scale if the area is clean when breeding season starts.

The area is also reported to be home to sea mammals. An incident occurring in the autumn may be less lethal than one occurring in the early spring, especially for the offspring that are more vulnerable just after birth.

There are also valuable wetland areas that may be severely impacted from an oil spill. Otherwise there are also many sites dedicated for human recreational activities in this area, but these are categorized with the priority C or D.

There are no registered deep water corals or fish spawning sites in the areas that may be affected by these two scenarios.

3 CONCLUSION

3.1 Relative comparison of consequences

3.1.1 Scenario 3A and B

Based on this generic comparative consequence analysis, the following conclusions are made:

	Init. release	T to impact	Rec. at sea	Oil on shore	Rec. cost	No. of MOB	Tug in time
Scenario 3A	1000 m^3	10h	45 m^3	953 m^3	190 MNOK	12	No
Scenario 3B	1000 m^3	70h	748 m^3	250 m^3	50 MNOK	98	Yes

3.1.2 Scenario 4A and B

Based on this generic comparative consequence analysis, the following conclusions are made:

	Init. release	T to impact	Rec. at sea	Oil on shore	Rec. cost	No. of MOB	Tug in time
Scenario 4A	20 000 m^3	12 h	325 m^3	8675 m^3	347 MNOK	131	No
Scenario 4B	20 000 m^3	no imp.	n/a	No oil	15 MNOK	n/a	Yes

3.1.3 Conclusion

An oil spill occurring along the new proposed route will have significantly more time (7 times in case of scenario 3) at sea until shoreline impact. The extended oil drift time at sea will enhance natural degradation of oil through evaporation and natural dispersion. It will also enable emergency towing or oil spill response that may significantly reduce the overall environmental impact. The highest benefit is expected to be for crude oil spills from tanker accidents.

Generally an oil spill accident happening in the early spring will have more potential environmental impact. Spring is the time when most species breed and young and immature animals are more sensitive to toxicity. Direct exposal to pollution or indirectly through digestion can increase mortality, behavior, reproduction and may also cause lethal effects for offspring.

The larger impact area of an oil spill occurring further away from the shore indicates that a higher number of sites may be exposed to the spill. However experience shows that the number of impact sites is not proportionate with the total impact area and may also be counter balanced by the lower concentration of oil (severity of impact) on each site. From past spills oil has been observed accumulating in patches. The extended drifting distance may decrease the impact intensity and hence ease the effect for the local populations within a region. This means that e.g. neighboring bird populations may not be effected, directly or through polluted or shortage of prey, to the same degree and migration between them decrease the overall impact. The same may be the result for a local fish stock, a seal or otter population etc.

In case of scenario 4B the oil spill will drift with the coastal current towards the North Sea. There is great uncertainty whether this may cause injuries for organisms in the water column or seabirds.

There are few negative effects of adopting the alternative route. The most important factor is a possible larger oil spill coastline impact area. For crude oils, this negative effect is counter balanced with the increased evaporation and natural degradation. For fuel oil this natural degradation effect is less notable. However, an oil spill response operation may even counter balance this negative effect.

References

Heggøy E, Johansen P-O, 2007 Johannessen P. Marinbiologisk undersøkelse i forbindelse med forliset av MS Server i 2007. SAM-Unifob rapport nr. 14-2007

Lorentsen, S.-H. (ed.), Byrkjeland, S., Flagstad, Ø., Heggberget, T.M., Larsen, T., Røv, N., Balstad, T., Haugland, T. & Østborg, G.M. 2008. Etterkantundersøkelser sjøfugl og oter etter MS Server-forliset januar 2007. NINA Rapport 336: 64 pp.

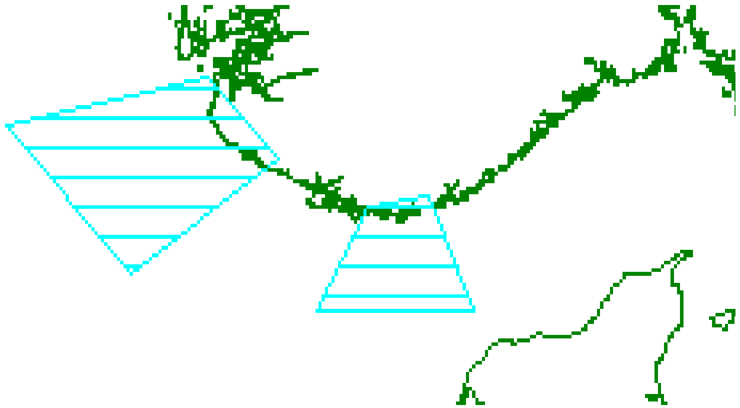
SFT 2000. Beredskap mot akutt forurensning; Modell for prioritering av miljøressurser ved akutte oljeutslipp langs kysten. Overgjødsling og Oljeforurensning TA 1765/2000.

Electronic sources:

DNMI, kilden.no
Biologi.no: www.biologi.no
Directorate of Fisheries; www.fiskeridir.no
SFT; www.sft.no - spesielt Publikasjoner - Olje & gass - statlig dimensjonering
Institute for Marine Research: www.imr.no
The Norwegian Coastal Administration; www.kystverket.no
SEAPOP (SEAbird POPulations); www.seapop.no
Wikipedia: www.wikipedia.no

Appendix 9 Accident figures for the scenario areas

Accident figures for the scenario areas for 2008 and 2025 collected from MARCS are given in tables below. The different table categories have been given the following colour keys:



	Accident frequency per year
	Spill accident frequency per year
	Oil spill volumes in tonnes per year

Today`s route 2008 - Egersund	Egersund						
Total accidents	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	8.90E-02	9.05E-03	5.47E-03	4.29E-03	1.35E-02	3.79E-03	5.29E-02
Struc	4.99E-02	5.15E-03	3.03E-03	2.58E-03	7.61E-03	2.09E-03	2.95E-02
FEX	4.37E-02	4.50E-03	2.65E-03	2.26E-03	6.65E-03	1.83E-03	2.58E-02
PGrd	4.28E-02	3.55E-03	4.00E-03	1.32E-03	6.61E-03	1.96E-03	2.54E-02
DGrd	1.33E+00	1.27E-01	8.05E-02	4.47E-02	2.07E-01	5.47E-02	8.13E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	5.89E-06	5.35E-07	6.59E-07	3.46E-07	1.20E-06	2.57E-07	2.90E-06
Total	1.55E+00	1.49E-01	9.56E-02	5.52E-02	2.41E-01	6.44E-02	9.47E-01
	Accident						
Spill accidents	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.49E-02	4.17E-03	1.84E-03	1.89E-03	1.35E-03	3.79E-04	5.29E-03
Struc	9.33E-03	2.97E-03	1.02E-03	1.42E-03	7.61E-04	2.09E-04	2.94E-03
FEX	8.16E-03	2.60E-03	8.94E-04	1.24E-03	6.65E-04	1.83E-04	2.58E-03
PGrd	7.65E-03	1.88E-03	1.67E-03	7.05E-04	6.61E-04	1.96E-04	2.54E-03
DGrd	2.10E-01	5.51E-02	2.85E-02	1.88E-02	2.07E-02	5.47E-03	8.13E-02
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	5.62E-07	1.16E-07	1.55E-07	7.33E-08	5.99E-08	1.28E-08	1.45E-07
Total	2.50E-01	6.67E-02	3.40E-02	2.41E-02	2.41E-02	6.44E-03	9.46E-02
	Risk	Area:					
Oil spill in tonnes	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	3.87E+01	8.30E+00	6.66E+00	2.29E+01	4.70E-01	5.30E-02	3.15E-01
Struc	5.41E+01	1.26E+01	3.72E+00	3.73E+01	2.76E-01	2.93E-02	1.76E-01
FEX	3.48E+01	7.86E+00	3.25E+00	2.32E+01	2.41E-01	2.57E-02	1.54E-01
PGrd	2.18E+01	4.28E+00	6.58E+00	1.06E+01	1.86E-01	2.91E-02	1.53E-01
DGrd	4.29E+02	1.15E+02	1.05E+02	1.97E+02	5.93E+00	6.96E-01	4.75E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	5.84E-04	2.80E-05	3.65E-04	1.25E-04	4.06E-05	4.73E-06	2.12E-05
Total	5.79E+02	1.48E+02	1.26E+02	2.91E+02	7.10E+00	8.33E-01	5.55E+00

Proposed route 2008 - Egersund	Egersund						
Total accidents	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	8.53E-02	6.12E-03	4.63E-03	3.25E-03	1.47E-02	4.13E-03	5.25E-02
Struc	6.42E-02	7.50E-03	4.22E-03	3.55E-03	1.40E-02	4.28E-03	3.06E-02
FEX	5.62E-02	6.56E-03	3.69E-03	3.10E-03	1.23E-02	3.74E-03	2.68E-02
PGrd	3.60E-02	1.77E-03	2.87E-03	6.94E-04	4.23E-03	1.10E-03	2.54E-02
DGrd	1.18E+00	7.32E-02	5.42E-02	2.59E-02	1.70E-01	3.90E-02	8.21E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	2.47E-03	6.14E-04	1.69E-04	4.77E-04	1.01E-03	2.00E-04	2.96E-06
Total	1.43E+00	9.58E-02	6.98E-02	3.69E-02	2.17E-01	5.25E-02	9.56E-01
Spill accidents	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.28E-02	2.71E-03	1.52E-03	1.40E-03	1.47E-03	4.13E-04	5.25E-03
Struc	1.21E-02	4.04E-03	1.34E-03	1.84E-03	1.40E-03	4.28E-04	3.06E-03
FEX	1.06E-02	3.53E-03	1.17E-03	1.61E-03	1.23E-03	3.74E-04	2.68E-03
PGrd	5.84E-03	1.06E-03	1.29E-03	4.17E-04	4.23E-04	1.10E-04	2.54E-03
DGrd	1.69E-01	3.40E-02	2.04E-02	1.14E-02	1.70E-02	3.90E-03	8.21E-02
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	2.00E-04	6.78E-05	1.87E-05	5.26E-05	5.03E-05	1.00E-05	1.48E-07
Total	2.10E-01	4.54E-02	2.57E-02	1.67E-02	2.16E-02	5.24E-03	9.56E-02
	Risk	Area:					
Oil spill in tonnes	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	3.23E+01	5.99E+00	5.35E+00	2.00E+01	6.31E-01	6.80E-02	3.20E-01
Struc	8.40E+01	2.15E+01	4.55E+00	5.67E+01	8.99E-01	8.05E-02	1.85E-01
FEX	5.37E+01	1.34E+01	3.97E+00	3.53E+01	7.86E-01	7.04E-02	1.62E-01
PGrd	1.56E+01	2.56E+00	5.17E+00	7.54E+00	1.14E-01	1.89E-02	1.53E-01
DGrd	2.94E+02	7.32E+01	7.51E+01	1.35E+02	5.23E+00	5.76E-01	4.81E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	3.13E-01	2.37E-02	3.04E-02	9.67E-02	1.55E-01	6.51E-03	2.18E-05
Total	4.80E+02	1.17E+02	9.42E+01	2.55E+02	7.81E+00	8.20E-01	5.63E+00

Today`s route 2025 - Egersund

Total accidents

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.77E-01	1.90E-02	5.25E-02	8.99E-03	2.25E-02	6.40E-03	6.71E-02
Struc	6.93E-02	7.74E-03	1.96E-02	3.89E-03	9.09E-03	2.50E-03	2.65E-02
FEX	6.06E-02	6.77E-03	1.71E-02	3.40E-03	7.95E-03	2.19E-03	2.32E-02
PGrd	5.77E-02	5.33E-03	1.73E-02	1.98E-03	7.90E-03	2.34E-03	2.28E-02
DGrd	1.82E+00	1.90E-01	5.13E-01	6.71E-02	2.47E-01	6.54E-02	7.32E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	7.72E-06	8.02E-07	2.05E-06	5.19E-07	1.43E-06	3.07E-07	2.61E-06
Total	2.18E+00	2.29E-01	6.20E-01	8.54E-02	2.95E-01	7.88E-02	8.71E-01

Spill accidents

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	3.76E-02	8.72E-03	1.54E-02	3.95E-03	2.25E-03	6.40E-04	6.70E-03
Struc	1.62E-02	4.47E-03	5.76E-03	2.14E-03	9.10E-04	2.50E-04	2.65E-03
FEX	1.41E-02	3.91E-03	5.04E-03	1.87E-03	7.95E-04	2.19E-04	2.32E-03
PGrd	1.37E-02	2.82E-03	6.51E-03	1.06E-03	7.90E-04	2.34E-04	2.28E-03
DGrd	3.69E-01	8.27E-02	1.54E-01	2.82E-02	2.47E-02	6.54E-03	7.32E-02
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	9.20E-07	1.74E-07	4.19E-07	1.10E-07	7.17E-08	1.54E-08	1.30E-07
Total	4.51E-01	1.03E-01	1.87E-01	3.72E-02	2.95E-02	7.88E-03	8.71E-02

Oil spill in tonnes

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.19E+02	1.73E+01	5.19E+01	4.80E+01	7.81E-01	8.94E-02	3.99E-01
Struc	9.53E+01	1.90E+01	1.96E+01	5.62E+01	3.30E-01	3.51E-02	1.59E-01
FEX	6.44E+01	1.18E+01	1.71E+01	3.50E+01	2.89E-01	3.07E-02	1.39E-01
PGrd	4.76E+01	6.42E+00	2.49E+01	1.59E+01	2.22E-01	3.48E-02	1.38E-01
DGrd	1.02E+03	1.73E+02	5.39E+02	2.96E+02	7.08E+00	8.32E-01	4.27E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	1.26E-03	4.20E-05	9.59E-04	1.87E-04	4.85E-05	5.65E-06	1.91E-05
Total	1.35E+03	2.27E+02	6.52E+02	4.51E+02	8.71E+00	1.02E+00	5.11E+00

Proposed route 2025 - Egersund

Total accidents

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.36E-01	1.10E-02	2.40E-02	1.25E-02	2.38E-02	6.23E-03	5.79E-02
Struc	9.56E-02	1.06E-02	2.64E-02	8.56E-03	1.74E-02	5.02E-03	2.76E-02
FEX	8.36E-02	9.30E-03	2.31E-02	7.49E-03	1.52E-02	4.39E-03	2.41E-02
PGrd	3.86E-02	2.66E-03	5.74E-03	1.04E-03	5.05E-03	1.32E-03	2.28E-02
DGrd	1.36E+00	1.04E-01	1.85E-01	6.77E-02	2.12E-01	4.67E-02	7.39E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	4.71E-03	9.22E-04	1.73E-03	7.15E-04	1.12E-03	2.23E-04	2.66E-06
Total	1.71E+00	1.39E-01	2.67E-01	9.80E-02	2.75E-01	6.38E-02	8.71E-01

Spill accidents

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	2.62E-02	5.34E-03	8.50E-03	3.51E-03	2.38E-03	6.23E-04	5.79E-03
Struc	2.28E-02	6.00E-03	8.70E-03	3.09E-03	1.74E-03	5.02E-04	2.75E-03
FEX	1.99E-02	5.25E-03	7.61E-03	2.71E-03	1.52E-03	4.39E-04	2.41E-03
PGrd	7.72E-03	1.59E-03	2.58E-03	6.24E-04	5.05E-04	1.32E-04	2.28E-03
DGrd	2.34E-01	5.04E-02	6.42E-02	2.00E-02	2.12E-02	4.67E-03	7.39E-02
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	4.39E-04	1.02E-04	1.91E-04	7.89E-05	5.61E-05	1.12E-05	1.33E-07
Total	3.11E-01	6.87E-02	9.18E-02	3.00E-02	2.74E-02	6.37E-03	8.71E-02

Oil spill in tonnes

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	5.62E+01	7.47E+00	1.53E+01	3.26E+01	6.02E-01	5.55E-02	1.91E-01
Struc	8.32E+01	1.70E+01	1.48E+01	5.08E+01	5.56E-01	4.78E-02	8.70E-02
FEX	5.58E+01	1.06E+01	1.29E+01	3.17E+01	4.86E-01	4.18E-02	7.62E-02
PGrd	1.29E+01	1.92E+00	5.17E+00	5.65E+00	6.79E-02	1.13E-02	6.90E-02
DGrd	3.01E+02	5.71E+01	1.15E+02	1.23E+02	3.43E+00	3.51E-01	2.19E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	3.35E-01	1.78E-02	1.55E-01	7.25E-02	8.67E-02	3.63E-03	1.01E-05
Total	5.09E+02	9.41E+01	1.63E+02	2.44E+02	5.23E+00	5.11E-01	2.61E+00

Today`s route 2008-Ryvingen — **Ryvingen**

Total accidents

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	2.47E-02	2.93E-03	1.44E-03	1.54E-03	4.04E-03	1.90E-03	1.29E-02
Struc	1.60E-02	1.89E-03	9.26E-04	9.81E-04	2.63E-03	1.15E-03	8.45E-03
FEX	1.40E-02	1.65E-03	8.10E-04	8.59E-04	2.30E-03	1.01E-03	7.40E-03
PGrd	3.64E-02	2.86E-03	7.27E-04	7.36E-04	2.37E-03	1.08E-03	2.86E-02
DGrd	5.04E-01	5.58E-02	2.61E-02	2.80E-02	7.31E-02	3.23E-02	2.89E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	5.95E-01	6.51E-02	3.00E-02	3.21E-02	8.44E-02	3.74E-02	3.46E-01

Spill accidents

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	4.50E-03	1.42E-03	4.68E-04	7.31E-04	4.04E-04	1.90E-04	1.29E-03
Struc	3.27E-03	1.16E-03	3.02E-04	5.90E-04	2.63E-04	1.15E-04	8.44E-04
FEX	2.86E-03	1.01E-03	2.64E-04	5.17E-04	2.30E-04	1.01E-04	7.39E-04
PGrd	4.68E-03	1.01E-03	2.03E-04	2.62E-04	2.37E-04	1.08E-04	2.86E-03
DGrd	8.09E-02	2.24E-02	8.06E-03	1.10E-02	7.31E-03	3.23E-03	2.89E-02
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	9.62E-02	2.70E-02	9.30E-03	1.31E-02	8.44E-03	3.74E-03	3.46E-02

Oil spill in tonnes

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.19E+01	3.17E+00	1.26E+00	7.25E+00	1.62E-01	2.03E-02	7.57E-02
Struc	1.88E+01	5.37E+00	7.91E-01	1.25E+01	1.05E-01	1.26E-02	4.96E-02
FEX	1.20E+01	3.34E+00	6.92E-01	7.77E+00	9.15E-02	1.10E-02	4.34E-02
PGrd	3.53E+00	1.45E+00	6.85E-01	1.16E+00	7.10E-02	9.17E-03	1.50E-01
DGrd	2.00E+02	5.34E+01	2.15E+01	1.20E+02	2.88E+00	3.51E-01	1.66E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	2.46E+02	6.68E+01	2.49E+01	1.49E+02	3.31E+00	4.04E-01	1.98E+00

Proposed route 2008 - Ryvingen — Ryvingen

Total accidents

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.86E-02	2.07E-03	9.38E-04	9.22E-04	2.77E-03	1.18E-03	1.07E-02
Struc	1.71E-02	2.41E-03	1.03E-03	1.07E-03	3.08E-03	1.07E-03	8.45E-03
FEX	1.50E-02	2.11E-03	9.01E-04	9.39E-04	2.69E-03	9.38E-04	7.40E-03
PGrd	2.86E-02	3.79E-06	2.16E-06	1.93E-06	6.94E-06	9.46E-07	2.86E-02
DGrd	4.11E-01	3.38E-02	1.43E-02	1.51E-02	4.35E-02	1.52E-02	2.89E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	4.90E-01	4.04E-02	1.72E-02	1.80E-02	5.20E-02	1.84E-02	3.44E-01

Spill accidents

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	3.20E-03	9.80E-04	3.13E-04	4.49E-04	2.77E-04	1.18E-04	1.07E-03
Struc	3.67E-03	1.43E-03	3.33E-04	6.47E-04	3.08E-04	1.07E-04	8.44E-04
FEX	3.21E-03	1.25E-03	2.91E-04	5.66E-04	2.69E-04	9.38E-05	7.39E-04
PGrd	2.87E-03	2.27E-06	9.70E-07	1.16E-06	6.95E-07	9.45E-08	2.86E-03
DGrd	5.67E-02	1.22E-02	4.27E-03	5.53E-03	4.35E-03	1.52E-03	2.89E-02
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	6.97E-02	1.58E-02	5.21E-03	7.20E-03	5.20E-03	1.84E-03	3.44E-02

Oil spill in tonnes

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	7.16E+00	2.07E+00	8.90E-01	4.02E+00	1.08E-01	1.35E-02	6.31E-02
Struc	1.96E+01	6.30E+00	9.93E-01	1.22E+01	1.20E-01	1.39E-02	4.96E-02
FEX	1.25E+01	3.92E+00	8.69E-01	7.56E+00	1.05E-01	1.21E-02	4.34E-02
PGrd	1.76E-01	6.35E-03	2.07E-03	1.69E-02	2.60E-04	1.72E-05	1.50E-01
DGrd	9.88E+01	2.79E+01	1.17E+01	5.57E+01	1.69E+00	1.98E-01	1.66E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	1.38E+02	4.02E+01	1.44E+01	7.94E+01	2.02E+00	2.37E-01	1.96E+00

Today`s route 2025- Ryvingen

Total accidents

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	3.15E-02	4.53E-03	2.82E-03	2.29E-03	5.62E-03	2.66E-03	1.36E-02
Struc	1.80E-02	2.58E-03	1.49E-03	1.29E-03	3.24E-03	1.42E-03	7.96E-03
FEX	1.57E-02	2.25E-03	1.31E-03	1.13E-03	2.83E-03	1.24E-03	6.96E-03
PGrd	3.71E-02	3.74E-03	9.10E-04	9.19E-04	2.97E-03	1.35E-03	2.72E-02
DGrd	5.62E-01	7.53E-02	4.70E-02	3.64E-02	9.04E-02	4.00E-02	2.73E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	6.64E-01	8.84E-02	5.35E-02	4.20E-02	1.05E-01	4.67E-02	3.28E-01

Spill accidentss

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	6.47E-03	2.23E-03	9.38E-04	1.12E-03	5.62E-04	2.65E-04	1.36E-03
Struc	4.17E-03	1.61E-03	5.04E-04	7.96E-04	3.24E-04	1.42E-04	7.95E-04
FEX	3.65E-03	1.41E-03	4.41E-04	6.97E-04	2.83E-04	1.24E-04	6.96E-04
PGrd	5.05E-03	1.32E-03	2.55E-04	3.28E-04	2.97E-04	1.35E-04	2.72E-03
DGrd	9.98E-02	3.05E-02	1.46E-02	1.45E-02	9.04E-03	4.00E-03	2.72E-02
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	1.19E-01	3.71E-02	1.67E-02	1.74E-02	1.05E-02	4.67E-03	3.28E-02

Oil spill in tonnes

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	1.90E+01	5.00E+00	2.68E+00	1.10E+01	2.26E-01	2.84E-02	8.01E-02
Struc	2.59E+01	7.47E+00	1.36E+00	1.69E+01	1.29E-01	1.55E-02	4.67E-02
FEX	1.65E+01	4.65E+00	1.19E+00	1.05E+01	1.13E-01	1.36E-02	4.08E-02
PGrd	4.46E+00	1.90E+00	8.58E-01	1.45E+00	8.90E-02	1.15E-02	1.43E-01
DGrd	2.79E+02	7.30E+01	4.12E+01	1.59E+02	3.56E+00	4.34E-01	1.56E+00
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	3.44E+02	9.20E+01	4.73E+01	1.99E+02	4.12E+00	5.03E-01	1.87E+00

Proposed route 2025 - Ryvingen

Total accidents

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	2.27E-02	3.25E-03	1.69E-03	1.42E-03	3.85E-03	1.65E-03	1.08E-02
Struc	1.92E-02	3.25E-03	1.48E-03	1.40E-03	3.80E-03	1.32E-03	7.96E-03
FEX	1.68E-02	2.84E-03	1.30E-03	1.23E-03	3.33E-03	1.16E-03	6.96E-03
PGrd	2.72E-02	5.69E-06	4.32E-06	2.89E-06	8.29E-06	1.13E-06	2.72E-02
DGrd	4.32E-01	4.59E-02	2.18E-02	1.99E-02	5.36E-02	1.87E-02	2.73E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	5.18E-01	5.52E-02	2.63E-02	2.39E-02	6.46E-02	2.28E-02	3.25E-01

Spill accidents

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	4.58E-03	1.61E-03	6.13E-04	7.30E-04	3.85E-04	1.65E-04	1.08E-03
Struc	4.64E-03	1.96E-03	5.04E-04	8.64E-04	3.80E-04	1.32E-04	7.95E-04
FEX	4.05E-03	1.71E-03	4.41E-04	7.55E-04	3.33E-04	1.16E-04	6.96E-04
PGrd	2.72E-03	3.41E-06	1.94E-06	1.74E-06	8.30E-07	1.13E-07	2.72E-03
DGrd	6.58E-02	1.68E-02	6.95E-03	7.52E-03	5.36E-03	1.87E-03	2.72E-02
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	8.18E-02	2.21E-02	8.51E-03	9.87E-03	6.46E-03	2.28E-03	3.25E-02

Oil spill in tonnes

	Total	CTank1	GTank2	OTank3	Cargo6	Other7	Other8
Collis	6.03E+00	1.72E+00	8.95E-01	3.29E+00	7.50E-02	9.41E-03	3.19E-02
Struc	1.34E+01	4.33E+00	7.41E-01	8.21E+00	7.40E-02	8.57E-03	2.33E-02
FEX	8.54E+00	2.69E+00	6.48E-01	5.10E+00	6.47E-02	7.49E-03	2.04E-02
PGrd	9.11E-02	4.77E-03	2.07E-03	1.27E-02	1.56E-04	1.03E-05	7.14E-02
DGrd	6.95E+01	1.95E+01	9.49E+00	3.86E+01	1.04E+00	1.22E-01	7.81E-01
PPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
DPlat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	9.76E+01	2.83E+01	1.18E+01	5.52E+01	1.26E+00	1.47E-01	9.28E-01

Appendix 10: Risk assessment of alternative tanker routing. Report from DNV

Safeguarding life property and the environment safeguarding life property and the environment safeguarding

DET NORSKE VERITAS

RISK ASSESSMENT OF ALTERNATIVE TANKER ROUTING

for

NORWEGIAN CENTRE FOR TRANSPORT RESEARCH

DNV PROJECT NO. 24427562
REVISION 2 – 22 JANUARY 2010

PREPARED BY: DR TIM FOWLER

REVIEWED BY: JOHN SPOUGE

APPROVED BY: DR TIM FOWLER

DET NORSKE VERITAS LTD

Palace House
3 Cathedral Street
London SE1 9DE
United Kingdom

Tel : + 44 (0) 20 7357 6080
Fax : + 44 (0) 20 7357 6048
http:\\www.dnv.com

Registered in England
No.: 1503799

MANAGING RISK

Executive Summary

The Norwegian Centre of Transport Research (NCTR) is leading a study to assess the risk reduction benefit of deep sea routing for oil tankers off the coast of Norway. NCTR contracted Det Norske Veritas (DNV) to perform the detailed risk analysis calculations because of DNV's considerable experience in marine risk assessment. This document reports the results of DNV's work.

Four distinct situations ("Cases") were evaluated as follows:

- Case A: This used marine traffic patterns from the year 2008 and the present tanker routes.
- Case B: This used marine traffic patterns from the year 2008 and the proposed new tanker routes.
- Case C: This used estimated marine traffic patterns for the year 2025 and the present tanker routes.
- Case D: This used estimated marine traffic patterns for the year 2025 and the proposed new tanker routes.

DNV calculated the following results for these 4 cases:

- The frequency of serious accidents for all ship types and all accident types.
- The frequency of cargo and bunker oil spilling accidents for oil tankers and chemical tankers (cargo spills only) and for bunker spills (all ship types).
- The risk of cargo oil spills (for oil tankers and chemical tankers) and bunker oil spills (all ship types).

Marine accident risks are expressed in terms of the expected (average) quantity of oil (cargo or bunker) lost from containment per year.

All results were obtained in both tabular form and in terms of the geographical positions of higher risk locations.

NCTR was responsible for all data collection tasks associated with this work, and were also responsible for interpreting the results of the risk assessments. DNV was responsible for checking the input data, presenting the input data into the risk model, data and results handling, and for generating the output tables and plots.

Finally, this report provides *examples* of the types of information generated by the risk modelling work. NCTR has been provided by email with many more detailed results (tables of results and plots) than those presented in this report. *The information in this report should not be interpreted without reference to these additional results.*

Contents

1. INTRODUCTION

1.1 Background

Commercial shipping results in a range of impacts to the wider environment, due to the intended routine release of materials such as exhaust gases, and of risks to the environment due to the potential unintended release of materials as a result of accidental events. Unfortunately shipping accidents can result in very severe impacts, particularly to coastal regions, due to the potential release of very large quantities of hazardous or ecotoxic cargo materials, such as crude oil, during accidents to shipping.

Prudent authorities which have the responsibility for pollution response in coastal regions seek to understand the risks to which they may need to respond in order that appropriate contingency plans and response options may be identified prior to an accident occurring. Prompt and effective spill response is considered to be a very important mitigation measure to reduce the environmental impacts if an accident occurs.

The Norwegian Centre of Transport Research (NCTR) is leading a study to assess the risk reduction benefit of alternative (deep sea) routing for oil tankers off the coast of Norway. NCTR contracted Det Norske Veritas (DNV) to perform the detailed risk analysis calculations because of our considerable experience in marine risk assessment. This document reports the results of DNV's work which, in turn, will be an input into the report written by NCTR.

1.2 Scope and Objective

The scope of this work is confined to the release of the following materials from ships due to accidental events:

- Crude oil and refined products carried as cargo by tankers.
- Bunker fuel oil carried by all ships.

Accidents in port approach and port areas are excluded from the scope of this work. The shipping patterns and other input data are characteristic of shipping operations in the year 2008. Shipping patterns (similar to today and new routes) have also been estimated by NCTR for the year 2025. The risks evaluated are restricted to the risks to the marine environment due to the accidental release of cargo oils and bunker fuel into the sea; human fatality and any other types of risk are excluded from the scope of this work. The risks to the marine environment are evaluated in terms of the frequency and quantity of material released into the environment. That is, DNV has not performed dispersion modelling or made estimates of the relative ecotoxicity of different materials within this report. Finally, an assessment of residual risk acceptability is also excluded from the scope of this work.

The objectives of this work are:

- To determine the risk benefit for deep water routing of oil tankers in 2008.
- To estimate the risk benefit for deep water routing of oil tankers in 2025.

DNV understand that this report will be an input into the wider project programme that is being performed and co-ordinated by NCTR. It was agreed that:

- NCTR would be responsible for all data collection activities and would provide all data to DNV.

- DNV would be responsible for entering the data into the marine risk model and calculating the results required.
- NCTR would be responsible for interpreting the results of the risk assessment.

This report describes the work performed by DNV.

2. RISK ASSESSEMNT APPROACH AND METHODOLOGY

2.1 Introduction

The risk assessment process can be summarised by the following points:

- What can happen, or hazard identification;
- How often will it happen, or accident frequency analysis;
- How bad will it be, or accident consequence analysis;
- Where is it likely to happen, which supports accident contingency planning;
- What can be done to stop it, or risk reduction analysis;
- Are risk reduction measures worth it, or cost benefit analysis;
- Are the residual risks, after the application of the selected risk reduction measures (if any) acceptable, or risk acceptance criteria.

DNV's project scope mainly addresses the first 4 points and explicitly excludes consideration of the last 2 points.

2.2 Hazard Identification

Analysis of historical ship accident data indicates that almost all open-water shipping losses (excepting causes such as war or piracy) can be categorised into the following generic accident types:

- Ship-ship collision: abbreviated by “collis”;
- Powered grounding (groundings which occur when the ship has the ability to navigate safely yet goes aground, such as the *Exxon Valdez*): abbreviated by “PGrd”;
- Drift grounding (groundings which occur when the ship is unable to navigate safely due to mechanical failure, such as the *Braer*): abbreviated by “DGrd”;
- Structural failure/ foundering whilst underway: abbreviated by “Struc”;
- Fire/ explosion whilst underway: abbreviated by “Fex”;
- Powered ship collision with fixed marine structures such as platforms or wind turbines (similar definition to powered grounding): abbreviated by “PPlat”;
- Drifting ship collision with fixed marine structures such as platforms or wind turbines (similar definition to drift grounding) : abbreviated by “DPlat”.

These generic accident types effectively represent the results of a high level marine transportation hazard identification (HAZID) exercise and are applicable for most marine transportation systems. DNV considers that this high level HAZID is sufficient for these risk calculations.

2.3 Risk Analysis Methodology

DNV has developed the Marine Accident Risk Calculation System (MARCS) to perform this type of calculation. MARCS is described in detail in Appendix I and the input data that is used by MARCS is shown in Appendix II.

This risk analysis methodology has been applied to the following ship types in this study, as described in more detail in Appendix II:

- Type 1: Chemical tankers and refined product tankers;
- Type 2: Gas tankers;
- Type 3: Oil (crude) tankers;
- Type 4: Not used;
- Type 5: Not used;
- Type 6: Cargo > 5000bt;
- Type 7: Other >5000bt;
- Type 8: All other.

Cargo oil spill risk is calculated from chemical tankers (Type 1) and oil tankers (Type 3). Bunker fuel oil risk spilt from bunker tanks (distinct from bunker fuel oil as a cargo) is calculated from all ship types.

2.4 Risk Analysis Results

The following types of results are presented in this report in Section 3 below:

- An analysis of traffic data in terms of:
    - Transits per day for each ship type (as defined within any one calculation location according to the key shown in Table 2.1). See Figure 3.1 as an example.
    - The total number of vessel-miles within the calculation area and within each defined sub-areas (see Figure 2.1). The sub-areas are defined to assist the additional analysis to be performed by NCTR.
- An analysis of total accident frequency (frequency of serious accidents per year but not necessarily involving cargo or bunker spill into the sea) in terms of:
    - The frequency of all accidents per year.
    - The total number of accidents per year as a function of vessel type and accident type within the calculation area and within each defined sub-areas (see Figure 2.1). The sub-areas are defined to assist the additional analysis to be performed by NCTR.
- An analysis of cargo oil or bunker oil spilling accident frequency (frequency of cargo or bunker spilling accidents per year) in terms of:
    - The frequency of all cargo oil or bunker oil spilling accidents per year (as defined within any one calculation location according to the key shown in Table 2.2). See Figure 3.2 as example.
    - The total number of cargo spilling accidents per year as a function of vessel type and accident type within the calculation area and within each defined sub-areas (see Figure 2.1). The sub-areas are defined to assist the additional analysis to be performed by NCTR.
- An analysis of cargo and bunker oil spilling accident risk (weight of cargo or bunker oil spilled into the sea per year) in terms of:

- The oil spilling risk of all accidents per year (as defined within any one calculation location according to the key shown in Table 2.3). See Figure 3.3 as an example.
- The cargo spill risk per year as a function of vessel type and accident type within the calculation area and within each defined sub-areas (see Figure 2.1). The sub-areas are defined to assist the additional analysis to be performed by NCTR.

Note that in this report the terms "cargo spill" or "cargo risk" also cover bunker fuel oil releases, though strictly bunker oil is not cargo.

See Appendix II for the definition of the terms study area and calculation location.

Table 2.1 Key to Ship Transit Plots

Colour	Transit Frequency (movements per day within each calculation location)
(grey)	0.05 to 0.1
(cyan)	0.1 to 0.5
(green)	0.5 to 1
(yellow)	1 to 5
(orange)	5 to 10
(red)	> 10

Table 2.2 Key to Accident Frequency Plots

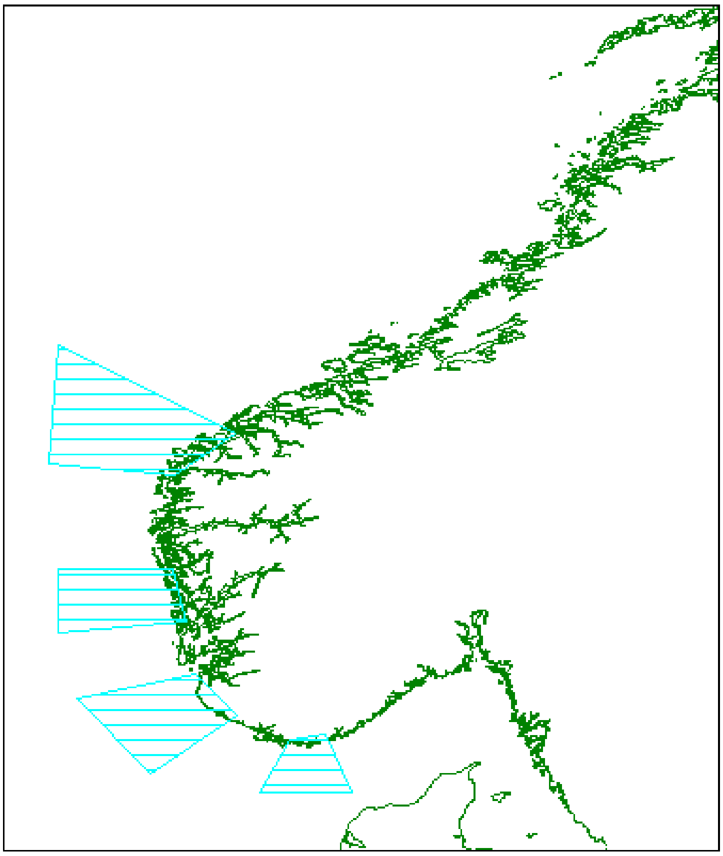
Colour	Accident Frequency (accidents per year within each calculation location)
(grey)	1.0 E-08 - 1.0 E-06
(cyan)	1.0 E-06 - 1.0 E-05
(green)	1.0 E-05 - 1.0 E-04
(yellow)	1.0 E-04 - 1.0 E-03
(orange)	1.0 E-03 - 1.0 E-02
(red)	> 1.0 E-02

Table 2.3 Key to Accident Risk Plots

Colour	Cargo Spill Risk (tonnes cargo spilt per year within each calculation location)
(grey)	1.0 E-06 – 1.0 E-05
(cyan)	1.0 E-05 – 1.0 E-04
(green)	1.0 E-04 – 1.0 E-02
(yellow)	1.0 E-02 – 1.0 E-01
(orange)	1.0 E-01 – 1.0
(red)	> 1.0

Note the terms study area (the total area under study), the study sub-areas (as defined in Figure 2.1) and the calculation location (each "pixel" of the calculation as determined by the calculation resolution) are described further in Appendix I and Appendix II.

Figure 2.1 Definition of Sub-Areas defined to aid the Analysis



It should be noted that 4 additional sub-areas were defined to enable the results to be presented in alternative ways. These additional sub-areas were requested by NCTR.

3. SUMMARY OF RISK RESULTS AND DISCUSSION

This section presents a summary of the results of the risk analysis for shipping in Norwegian waters. The complete risk results have been sent to NCTR by email.

3.1 Analysis of Traffic Data

Table 3.1 shows the analysis of the total traffic data (number of vessel miles per year) that is used as the basis of the risk results in this study.

Table 3.1 Analysis of Total Traffic Data (nautical miles per year) in the Study Area for each Case

	Case A	Case B	Case C	Case D
Chemical Tanker	9.58E+05	1.21E+06	1.42E+06	1.57E+06
Gas Tanker	3.27E+05	3.85E+05	1.45E+06	2.11E+06
Oil Tanker	6.09E+05	8.63E+05	9.03E+05	1.57E+06
Cargo	1.25E+06	2.21E+06	1.50E+06	2.73E+06
Other >5000bt	4.64E+05	6.91E+05	5.54E+05	8.17E+05
Other	4.43E+06	4.52E+06	4.02E+06	4.09E+06
Total	8.04E+06	9.88E+06	9.85E+06	1.29E+07

Table 3.1 indicates that a total of between 8 and 13 million ship-miles are travelled within the defined study area per year. Assuming an average ship speed of 12 knots, this corresponds to an average of about 95 ships in the study area at any one time. More detailed traffic results have been supplied by email.

Figure 3.1 shows the geographical distribution of all traffic types for Case A.

Figure 3.1 Example Ship Transit Plot for Case A excluding Traffic Type 8 (key in Table 2.1)

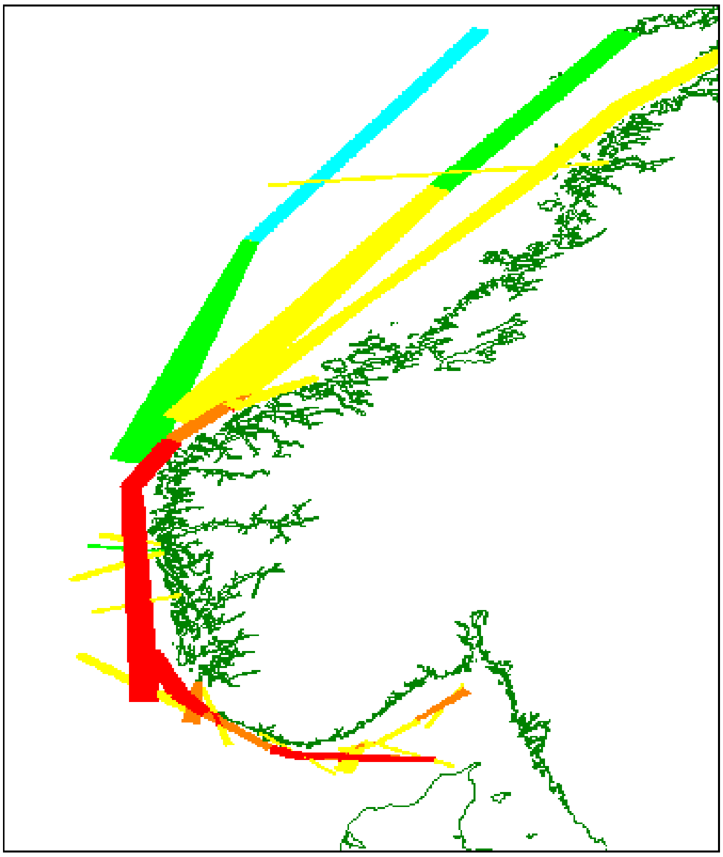


Table 3.2 summarises the traffic plots that were prepared and transmitted to NCTR.

Table 3.2 Definition of Traffic Plots Generated

	Plot File Names			
Plot Description	**Case A**	**Case B**	**Case C**	**Case D**
All traffic except Type 8	A-TraffAll.bmp	B-TraffAll.bmp	C-TraffAll.bmp	D-TraffAll.bmp
Traffic for chemical (Type 1) and oil tankers (Type 3)	A-Traf13.bmp	B-Traf13.bmp	C-Traf13.bmp	D-Traf13.bmp

3.2 Accident Frequency and Spilling Accident Frequency Results

Detailed accident frequency results have been sent to NCTR by email. These results include:

- Accident frequency (accidents per year) by ship type and accident type.
- Cargo and bunker fuel oil spilling frequency (spilling accidents per year) by ship type and accident type.
- Cargo and bunker fuel oil risks (average tonnes of oil lost from containment per year) by ship type and accident type.

Each of the above results are also shown by sub-area and by type of material spilt.

Figure 3.2 shows an example plot of the frequency of all cargo spilling accidents for chemical tankers (Type 1) and oil tankers (Type 3) combined for Case A. Similar plots for other cases were sent to NCTR by email.

Figure 3.2 Example Spilling Accident Frequency Plot for Case A (see Table 2.2 for key)

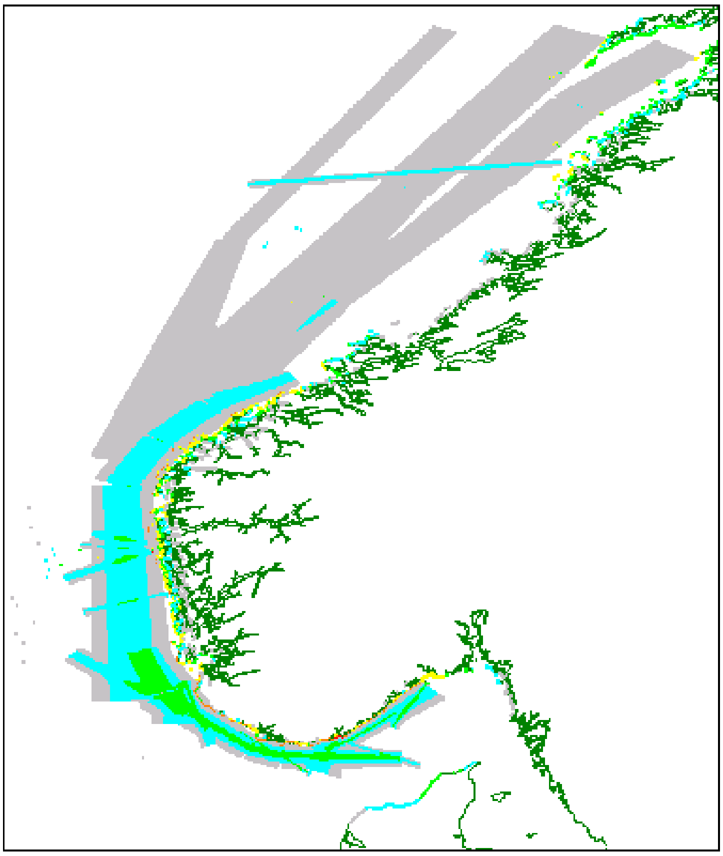


Table 3.3 summarises the spilling accident frequency plots that were prepared and transmitted to NCTR.

Table 3.3 Definition of Spilling Accident Frequency Plots Generated

	Plot File Names			
Plot Description	**Case A**	**Case B**	**Case C**	**Case D**
Bunker spills from all traffic plus cargo oil spill from chemical tankers (Type 1) and oil tankers (Type 3)	A-AllSpillFreq.bmp	B-AllSpillFreq.bmp	C-AllSpillFreq.bmp	D-AllSpillFreq.bmp

3.3 Cargo Spill Risk Results

Detailed accident risk results have been sent to NCTR by email. These results include:

- Cargo and bunker fuel oil risks (average tonnes of oil lost from containment per year) by ship type and accident type. These results are also shown by sub-area and by type of material spilt.

Figure 3.3 shows an example plot of the risk of all cargo spilling accidents for chemical tankers (Type 1) and oil tankers (Type 3) combined for Case A. Similar plots for other cases were sent to NCTR by email.

Figure 3.3 Example Accident Risk Plot of Cargo Oil Spilling Risk for Chemical Tankers and Oil Tankers for Case A (see Table 2.3 for key)

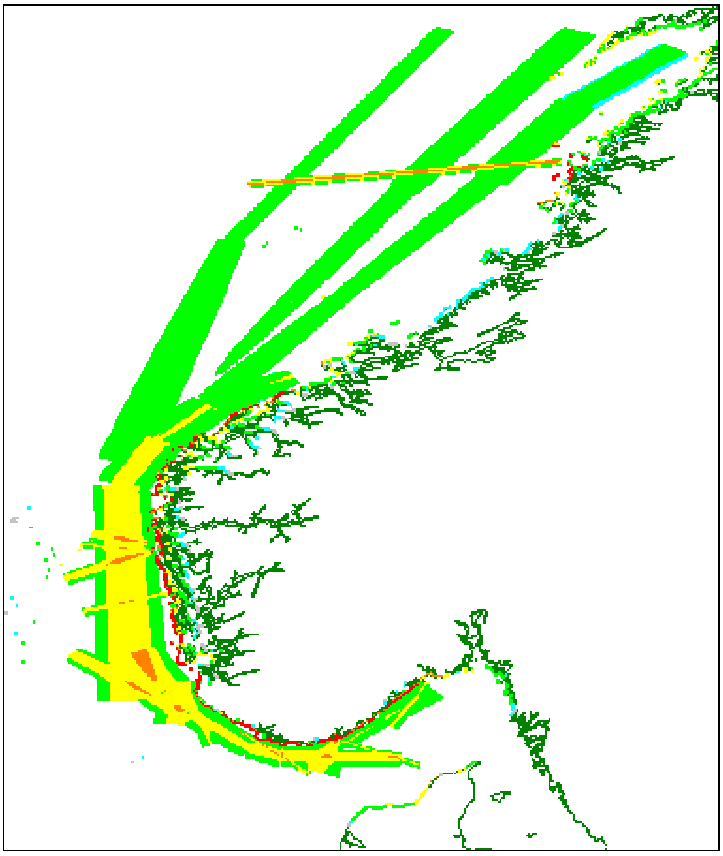


Table 3.4 summarises the oil spill accident risk plots that were prepared and transmitted to NCTR.

Table 3.4 Definition of Oil Spill Accident Risk Plots Generated

	Plot File Names			
Plot Description	**Case A**	**Case B**	**Case C**	**Case D**
Cargo oil spill risk from chemical tankers (Type 1) and from oil tankers (Type 3)	A-13Rsk.bmp	B-13Rsk.bmp	C-13Rsk.bmp	D-13Rsk.bmp
Bunker oil spill risk from all traffic types and cargo oil spill from chemical tankers (Type 1) and oil tankers (Type 3)	A-AllRsk.bmp	B-AllRsk.bmp	C-AllRsk.bmp	D-AllRsk.bmp

4. SUMMARY

A marine risk analysis of the Norwegian sector of the North Sea has been performed. The results show the relative risks for 4 different marine traffic scenarios.

This report provides *examples* of the types of information generated by the risk modelling work. NCTR has been provided by email with much more detailed results (tables of results and plots) than those presented in this report. *The information in this report should not be interpreted without reference to these additional results.*

NCTR was responsible for input data quality and for the interpretation of the results.

Visiting and postal address:
Institute of Transport Economics
Gaustadalléen 21
NO 0349 Oslo

Telephone: +47 22 57 38 00
Telefax: +47 22 60 92 00
E-mail: toi@toi.no

www.toi.no

Institute of Transport Economics
Norwegian Centre for Transport Research

- carries out research for the benefit of society and industry
- has a research staff of around 70 highly qualified staff working in various areas of transport research
- co-operates with a number of organisations, research institutes and universities in Norway and in other countries
- carries out high quality research and assessment projects within topics such as traffic safety, public transport, the environment, travel behaviour, tourism, planning, decision-making processes, transport economics, and freight
- publishes research findings in the Centre's own report series, on the Internet, in the periodical "Samferdsel", as well as in national and international scientific journals and publications
- participates in the Oslo Centre for Interdisciplinary Environmental and Social Research (CIENS) located near the University of Oslo