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ARTICLE

Oil spill risk analysis of routeing heavy ship traffic in Norwegian waters

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Abstract Norwegian authorities have for a long time been concerned about the risk of oil spills outside the Norwegian coast. One of the key measures adopted has been to reduce the risk of ship accidents by imposing sailing routes for heavy ship traffic (over 5,000 gross tonnages) with high environmental risk potential farther away from part of the coast. This article is based upon two reports which conducted risk assessments of imposing such sailing routes outside the entire Norwegian coast. These routes were proposed by an expert group consisting of relevant stakeholders. Data of traffic pattern and number of sailing were collected for the year 2008 using the universal Automatic Identification System (AIS). The proposed route was compared with 2008 traffic pattern in regard to the accident frequencies and the expected oil spills per year. An accident and oil spilling simulation program called MARCS was used to simulate these results. After conducting a traffic forecast for the year 2025, the simulation was again run and the results compared with the year 2008. In total, the proposed route is expected to reduce oil spills by 590 t per year in 2008 and by 3670 t in 2025. The main reason for this substantial reduction is that the number of groundings is reduced because of the distance from the shore being increased. The reduction was particularly strong for tankers.

Keywords Marine traffic · Environment · Simulation · Accident probabilities · Oil spill

1 Introduction

Norwegian authorities have for a long time been concerned about the risk of oil spills. One of the key measures adopted to reduce the risk of ship accidents and oil spills is to impose sailing routes for heavy ship traffic (over 5,000 GT) with high environmental risk potential farther away from the rest of the Norwegian.

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An expert group consisting of relevant stakeholders got the task to propose a route alongside the remaining coast. Their proposal will be referred to as the “proposed route”, while 2008 traffic pattern will be referred to as “2008 route”.

The Norwegian Coastal Administration (NCA) commissioned The Institute of Transport Economics (TØI) to conduct a risk assessment of the proposed route which led to two reports this article is based upon (Akhtar and Hansen 2009; Akhtar and Jean-Hansen 2009)

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 implemented.

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

1.1 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.

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 a 60% increase in the oil transport and a tenfold increase in the gas tanker transport (Frantzen and Bambulyak 2008).

The Norwegian Sea is rich on natural resources, thus being of great economical interest. Along with the fishery resources, it also has huge resources 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 2008 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 carries approximately 19.5 million individual sea birds and 4.5 million breeding pairs (Loeng and Drinkwater 2007).

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 (Frantzen and Bambulyak 2008). 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 2006).

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-t 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 t 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).

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.

The Norwegian authorities wished to examine the consequences of prolonging the imposed route along the entire coast. The idea 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.

2 Material and method

The approach adopted is to compare the proposed route with 2008 route given traffic data of 2008 and 2025 by simulating the number of accidents in each route. The traffic information of 2008 was gathered from the universal Automatic Identification System's (AIS) data, and traffic patterns were defined as routes of 2008 by using the AIS charts. These routes were then compared with the new purposed routes. An accident and risk simulation programme called MARCS, developed by DNV Technica, was used for this purpose.

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

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

By first defining the routes of 2008 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 defined routes and 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 accident simulation program.

2008 routes have no separation schemes. However, the oil transport flow in the Norwegian 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. The rest of the traffic was defined as constantly half loaded.

In the case of drifting or other emergency situations, collisions can occur with these structures leading to oil spill, loss of ship etc. Therefore, information about the installations at sea, vessels have to navigate past, like platforms, wind parks etc. was also inserted into the MARCS program.

When simulating the different probabilities for the proposed route, all vessel types except for “all other vessels” were moved to the proposed lanes. These vessels are not considered to have high potential environmental risk potential. Even smaller ships which do not carry AIS are also assumed to have the same volume and traffic patterns in both routes, their effect is assumed negligible, and they are thus not taken into account in the simulation.

2.1 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. AIS information is transmitted between vessels, from vessels to shore, or vice versa. In simple terms, AIS is a technology to make ships “visible” to each other. 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 et al. 2006).

3 The simulation (MARCS)

The Marine Accident Risk Calculation System (MARCS) was developed by Det Norske Veritas (DNV). The marine traffic image data used by MARCS is a representation of the actual flows of traffic within the calculation area. MARCS uses various models to calculate the probabilities and frequencies of collision and oil spills; these models are: the Collision Model, the Powered Grounding and Powered Collision Models, the Drift Grounding and Drift Collision Models, Repair Recovery Model, Recovery of Control by Emergency Tow, Recovery of Control by Anchoring, the Structural Failure Model and the Fire and Explosion Model (Thevik et al. 2002). The modeling methodology is shown in Fig. 1. Fault and event tree models, and historical accident statistics are used to deduce accident frequency and accident consequence parameters for each accident type. These are combined with data on shipping lanes and environmental data such as wind, sea state,

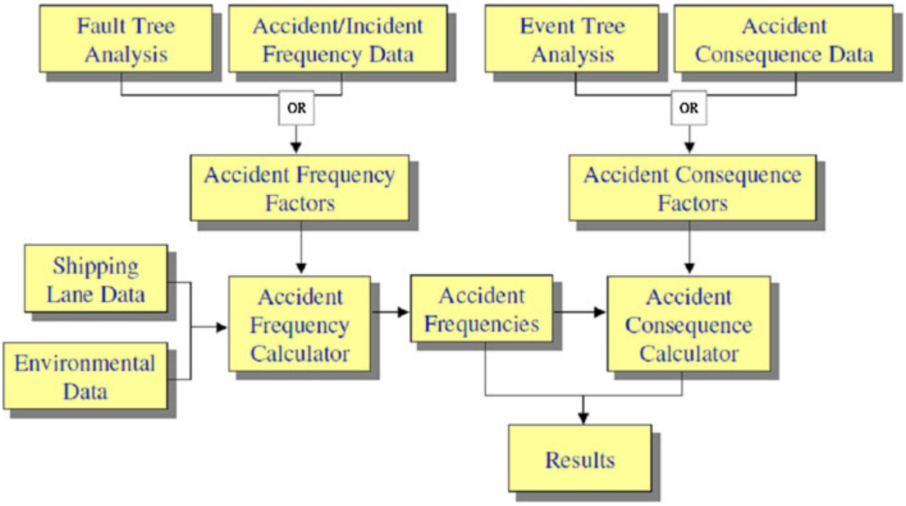

Fig. 1 Block diagram of the MARCS model (Fowler 2009)

coastal location and visibility to produce accident and spill risks. The movement of ships is modeled assuming a Gaussian distribution of ships across lanes and a speed distribution along lanes based on observed speeds of different vessel types (Fowler 2009).

The data needed by MARCS model to run a simulation are classified into four 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.

In our research the shipping lane data was collected using the AIS database. The environment data and external data were provided by the NCA, while the internal operational data and external operational data were provided by the DNV.

The DNV obtained these data by using either worldwide data or frequency factors obtained from fault tree analysis or location specific survey data. The data used in the simulation was from the DNV which 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

Similar data are published by the Norwegian Maritime Directorate every year (Directorate 2011). Two simulations were run, one for 2008 route and one for the proposed route.

4 The routes

The AIS data was used to plot all vessels of 100-m length or more for the period 2008–2009. One hundred metres was chosen after checking the AIS files and confirming that all tankers were at least 100 m.

The plots in Table 1 yield the typically used routes for large vessels today. A single sailing is marked with a yellow line in 2008 routes. Areas with high density are marked red. On the basis of these traffic data, 2008 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 the plots, 2008 routes are indicated by the parallel lines running along the

Table 1 2008 route and the proposed route

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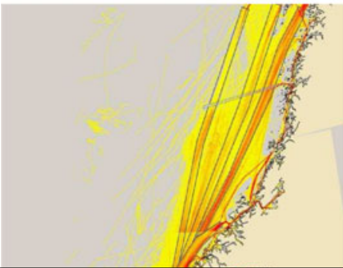
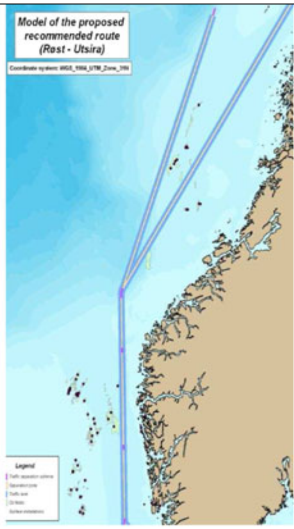
<tr><th></th><th>2008 route</th><th>Proposed route</th></tr>
<tr><td>Mid</td><td></td><td rowspan="2">
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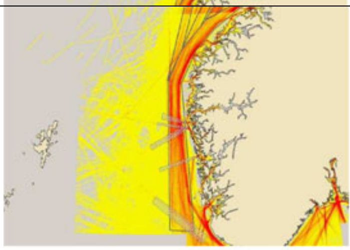
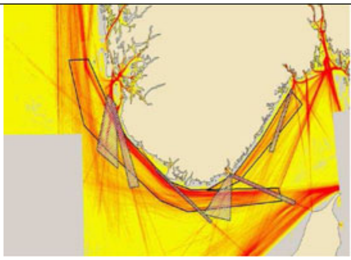
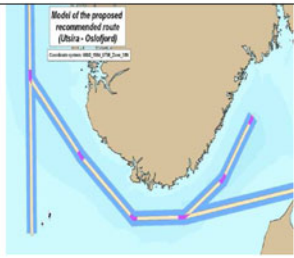
<tr><td>West</td><td></td></tr>
<tr><td>South</td><td></td><td>
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coast. The crossing lanes are indicated as shaded grey areas. In our AIS data, ships sailing far of the coast are not taken into account. The proposed route which had been identified by an expert group consisting of relevant stakeholders was assumed to not influence the crossing traffic mostly being from the platforms to the mainland. The crossing lanes were thus held equal for both simulations. The proposed route will lead to an increase on the total sailing distance. This will also lead to increased costs for ship owners.

5 Traffic forecast 2025

The ships sailing in the Norwegian fairways will be of many different nationalities, but the traffic is dominated by vessels linked to the offshore activities in Norwegian and Russian areas. Along the fairway outside the Norwegian coastline, ships to and from the Norwegian ports dominate the traffic.

Passenger traffic is limited and predominantly consists of cruise ships (> 5000 GT) coming from Europe and America visiting Norwegian fjords, North Cape and the coast around Svalbard. Oil and gas fields are currently being developed in the northern area of the study area, and further developments both on Russian and Norwegian fields are likely in the period 2008–2025. Most of the oil and gas produced in these areas has to be exported by ship from the fields to the markets in Europe and North America. Thus, the numbers of oil and gas tankers are expected to increase.

In addition, small tankers carrying fuel to the fishing fleet, oil and gas for residential heating etc. and other types of cargo ships will be travelling along the 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. Russian trawlers also deliver fish to Norwegian ports.

Our prognosis was developed by splitting Norway geographically into six parts due to differentiated traffic developments. By assessing the traffic in these six areas and by analyzing the oil and gas shipments plan from the NCA and from internationally published reports, a forecast was developed. The forecast was divided into two, one for tankers and one for non-tankers larger than 5000 GT.

The forecast given in Fig. 2 is based on expected export figures from the Shtokman field given by Frantzen and Bambulyak (2008), as well as on forecasts of the transport of oil and gas from the Norwegian oil and gas fields given by Hovi and Madslien (2008). According to these prognoses, tanker traffic is expected to increase from 2014 onward, notably gas tanker traffic. This is closely related to the planned development of the gas production from the Shtokman field. Oil tanker traffic is also expected to increase, but to a lesser extent. These developments will surely lead to changes in the size of the ships. However, these changes are not taken into account in the forecast.

In addition to the tanker transit traffic given in Fig. 2, there is also tanker traffic to and from the oil and gas fields in the North and Norwegian Sea and product tankers trafficking Norwegian refinery ports. Also, an increase in the product tanker traffic going to and from Norwegian ports is expected. Traffic to and from the oil and gas

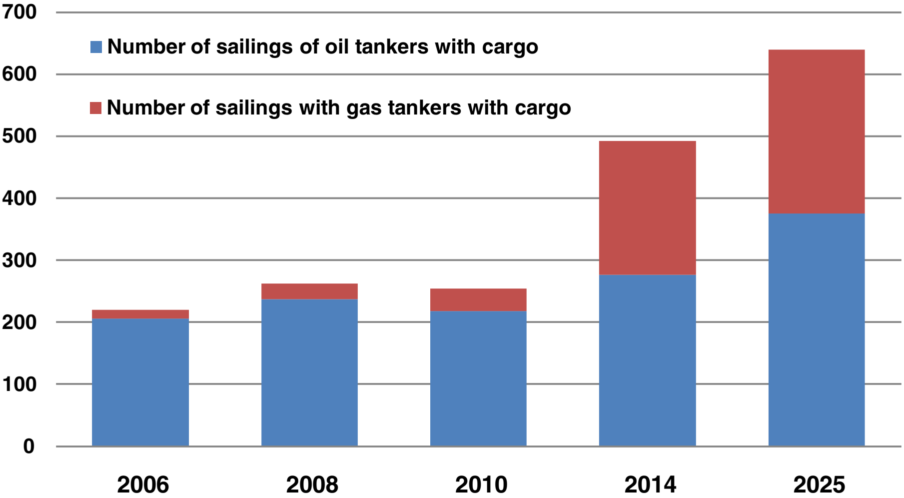


Fig. 2 Forecast of number of sailing—transit tankers

fields in the Norwegian and North Sea is, however, expected to remain stable. Figure 3 presents the forecast of the total tanker traffic between the entire study areas distributed by traffic types.

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. It is further assumed that the environmental and operational factors are stable from 2008 to 2025.

Table 2 gives the traffic volume data for 2008 route and the proposed route both for 2008 and 2025 distributed by type of ship. The numbers are aggregated per ship type by MARCS. The table indicates that a total of between 8 and 13

Fig. 3 Forecast number of sailings per year—total number of tankers

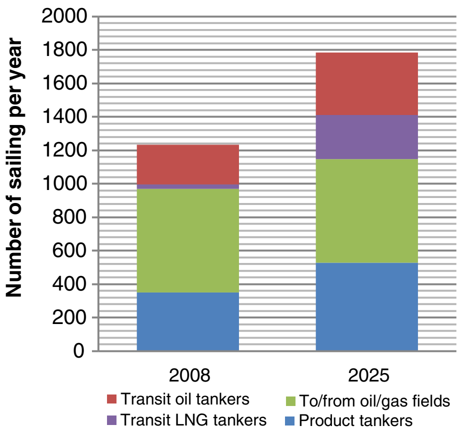
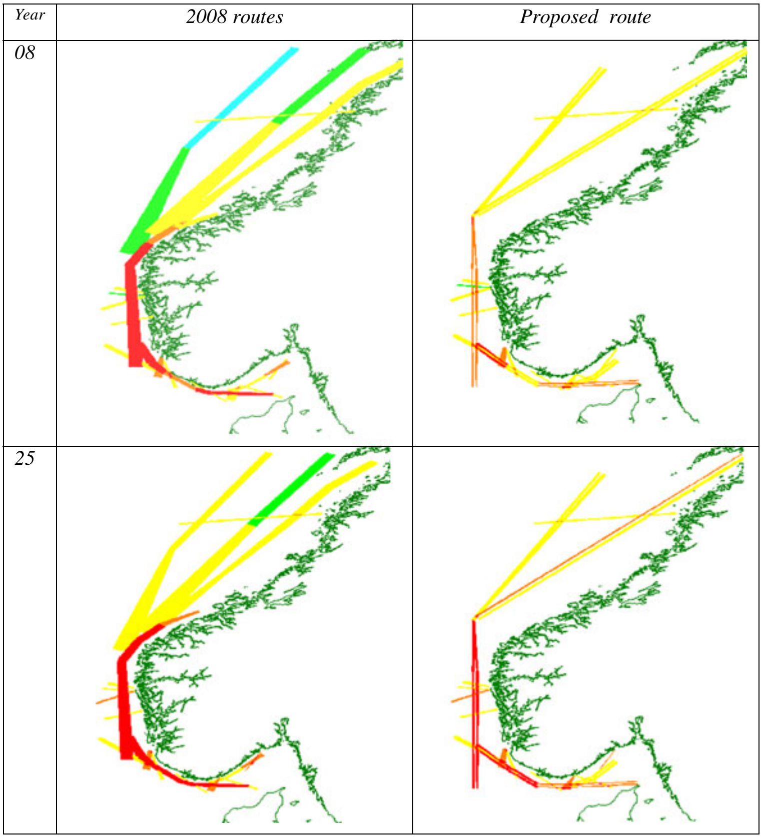


Table 2 The total traffic volume (in 1000 nautical miles) in 2008 and 2025 distributed by type of ship on 2008 routes and on the proposed route

	2008 routes Traffic of 2008	Proposed route Traffic 2008	2008 routes Traffic 2025	Proposed route Traffic 2025
Chemical tanker	958	1210	1420	1570
Gas tanker	327	385	1450	2110
Oil tanker	609	863	903	1570
Cargo ships >5000 GT	1250	2210	1500	2730
Other ships >5000 GT	464	691	554	817
All other vessels	4430	4520	4020	4090
Total	8040	9880	9850	12900

million ships-miles is travelled within the defined study area per year. With the assumed speed of 12 knots, this corresponds to an average of about 95 ships at

Table 3 Traffic plots for all vessels above 5000 GT in 2008 and 2025 on “2008 route” and on the proposed route



2008 traffic (2008) is given in the top left diagram; estimated traffic on the proposed route in 2008 is given in top right diagram. Traffic forecasts for 2025 on 2008 route are given in the bottom left diagram and on the proposed route in the bottom right diagram

Table 4 Key to ship traffic plots

Colour	Traffic frequency (ship movements per day within each location)
	0.05 to 0.1
	0.1 to 0.5
	0.5 to 1
	1 to 5
	5 to 10
	> 10

any one time. These traffic figures are used as the basis for the risk calculations presented later in the article.

From Table 2 it is clear that implementing the proposed route will increase the traffic volume of all ship types, but only marginally for "all other vessels". The forecast for 2025 reveals a substantial increase in the traffic volume of tankers, notably gas tankers. Traffic volumes of "all other vessels" are expected to decrease in 2025, due to a decreasing number of fishing vessels.

The ship traffic volumes are visualized in Table 3. Table 4 shows the keys for reading these 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. Vessels smaller than 5000 GT have been excluded from the diagrams; however, they are included in the simulations.

6 Simulation results

The accident and oil spill calculations were 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

Table 5 Expected accident frequencies per year

	Total	Chemical tanker	Gas tanker	Oil tanker	Cargo >5000 GT	Other vessels >5000 GT	Rest
"2008 routes" 2008	8.26	1.01	0.42	0.51	1.28	0.49	4.55
Proposed route	7.77	0.70	0.31	0.48	1.25	0.46	4.58
"2008 routes" 2025	10.30	1.51	1.70	0.77	1.55	0.60	4.20
Proposed route 2025	9.11	0.95	0.97	0.87	1.57	0.56	4.19

Table 6 Expected spilling accident frequencies per year

	Total	Chemical tanker	Gas tanker	Oil tanker	Cargo >5000 GT	Other vessels >5000 GT	Rest
"2008 routes" 2008	1.42	0.43	0.15	0.22	0.13	0.05	0.46
Proposed route	1.23	0.30	0.11	0.20	0.12	0.05	0.46
"2008 routes" 2025	2.13	0.64	0.53	0.33	0.16	0.06	0.42
Proposed route 2025	1.70	0.42	0.31	0.34	0.16	0.06	0.42

Tables 5, 6, 7, 8 and 9 present the expected accident frequency per year given traffic volumes and ship type distributions of 2008 and 2025 for the routes travelled today and for the proposed new route.

From Table 5 it is clear that the total number of accident is decreased with the proposed route. However, oil tanker and huge cargo ship accidents are somewhat increased for the year 2025. The same pattern is in Table 6 which shows the expected oil spilling accidents. The expected number of spill accidents is decreased with the proposed route. This is true both for the total number of accidents and for accidents involving chemical tankers and gas tankers. For oil tankers there is a small increase in the expected number of oil spill accidents when the proposed route is adopted, for the year 2025 (Table 8). The main reason for this effect is probably that lanes in the proposed route narrows the traffic and thus increases the probability of a collision. The average spill size is the same for 2008 routes, while it is lower in the proposed routes. This is probably due to fewer grounding accidents and fewer serious high speed collisions since the traffic is separated and thus moving in the same direction in the lanes. The effect is shown stronger in the 2025 traffic because the ships volume is higher. Tables 7 and 8 show the spilling accident frequencies by accident type and the expected oil spill by accident type. They clearly show that power groundings and drifts groundings are the major contributors of oil spills. The fire and explosion frequencies increase in the proposed routes, because the average sailing distance and sailing time increase.

Oil tankers are of particular interest in the present study because they contribute to the vast majority of oil spills. For oil tankers the proposed route has particularly beneficial effects. One important reason for this is that grounding accidents are reduced (Akhtar and Hansen 2009). Figure 4 presents the simulated oil spill volumes from oil tankers and the rest of the fleet on 2008 route and on the proposed new route in 2008 and 2025.

Table 7 Expected spilling accidents frequencies per year by accident type

	Total	Collision	Structural failure	Fire and explosions	Power groundings	Drift groundings	Power groundings on objects in the route	Drift groundings on objects in the route
"2008 routes" 2008	1.42	0.06	0.06	0.05	0.22	1.03	0.00	0.00
Proposed route	1.23	0.05	0.07	0.07	0.22	0.82	0.00	0.00
"2008 routes" 2025	2.13	0.13	0.09	0.08	0.32	1.51	0.00	0.00
Proposed route 2025	1.70	0.09	0.12	0.10	0.30	1.08	0.00	0.00

Table 8 Expected oil spills in tonnes per year

	Total	Chemical tanker	Gas tanker	Oil tanker	Cargo >5000 GT	Other vessels >5000 GT	Rest
"2008 routes" 2008	5130	1080	430	3530	58	6	27
Proposed route	4540	875	314	3240	75	6	27
"2008 routes" 2025	8710	1610	1670	5330	70	7	25
Proposed route 2025	5040	729	509	3740	52	4	13

Figure 5 has been constructed by calculating the effects of the proposed route using Tables 5, 7 and 8. We see that transferring ship traffic to the proposed new route gives a 6% reduction in all accidents and a 13% reduction in oil spill accidents and 12% in oil spill including bunkers oil spill in 2008. For 2025 the numbers are 12, 20 and 42%. However, only the oil spill reductions are calculated to have a statistically significant change for 2008 and 2025.

7 Discussion and conclusions

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 route is expected to reduce oil spills by 590 t per year in 2008 and by 3670 t in 2025. The main reason for this substantial reduction is that the number of groundings is reduced since the distance from the shore is increased. The reduction is particularly strong for tankers. The increased costs for ships owners because of the change in sailing distance could maybe be somewhat balanced by decreased insurance costs because of lower risks.

MARCS simulations were restricted to accidents affecting the marine environment, while accidents in port approach and port areas are not. The simulation does not take into account the possible higher alertness of the crew and easier navigation which follows by the separation of the traffic. Neither does the simulation adjust for the positive experiences derived from traffic separations schemes elsewhere in the world (IMO 2009). Accordingly it is possible that our simulation overestimates the accident frequency of oil tankers in 2025. MARCS bases its calculation and predictions on historical data. One should therefore bear in mind that the limited historical data will often have a large variance, which is not shown in the simulation results.

Table 9 Expected oil spill by accident type, in tonnes per year

	Total	Collision	Structural failure	Fire and explosions	Power groundings	Drift groundings	Power groundings on objects in the route	Drift groundings on objects in the route
"2008 routes" 2008	5130	195	463	292	1580	2600	1.43	1.47
Proposed route	4540	149	613	387	1510	1870	1.33	2.72
"2008 routes" 2025	8710	456	736	474	2420	4620	2.16	2.54
Proposed route 2025	5040	231	611	394	1890	1910	1.97	3.46

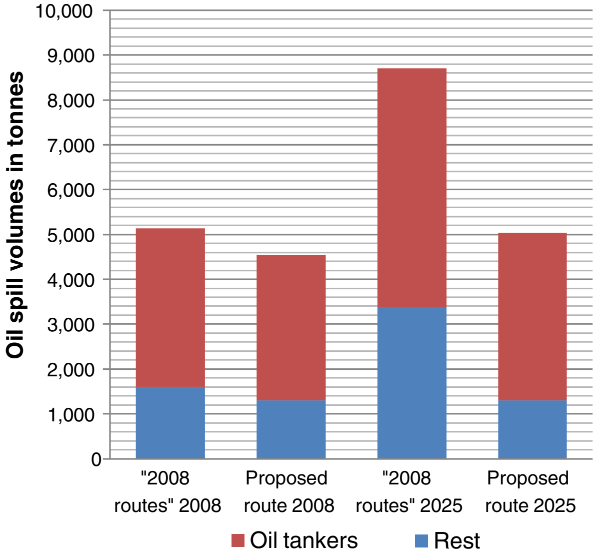


Fig. 4 Expected oil spill volumes from oil tankers and the rest of the fleet in tonnes, including bunkers oil on 2008 route and the proposed route with traffic data for 2008 and 2025

Another effect of the transfer of ship traffic to the proposed 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.

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.

Summing up the results, it seems clear that implementing the proposed route for tankers and vessels above 5000 GT will lower for probabilities of accident and oil spills including bunkers oil spills and reduces 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.

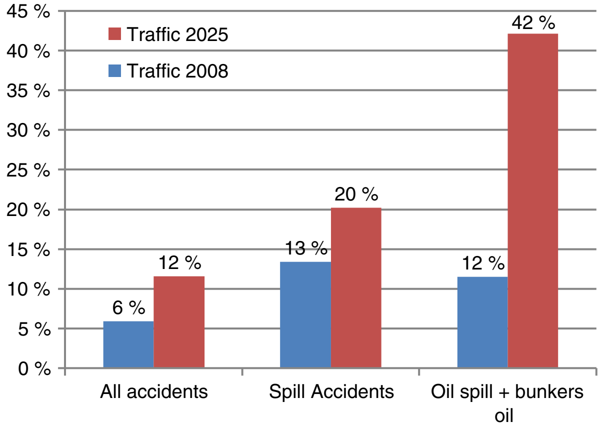


Fig. 5 Expected effects of proposed routeing. Per cent change in all accidents, oil spill accidents and the volume of oil spills with traffic data for 2008 and 2025

Glossary

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
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 km
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.

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