

Modelling of dynamic risk for enhanced ship monitoring and risk reduction

Magnus Strandmyr Eide¹⁾, Øyvind Endresen¹⁾, Kjell Røang²⁾, Jon Leon Ervik³⁾

¹⁾ Det Norske Veritas Research & Innovation, Norway

²⁾ Christian Mikkelsen Research

³⁾ The Norwegian Coastal Administration

Abstract

Oil spill data indicate that oil spill volumes and clean up cost for drift grounding accidents are higher compared to other accident types. A typical drift grounding accident with oil spill may cost up to 500 millions US dollars, depending on weather and stranding area. Studies indicate high potential for risk reduction in shore based support systems, such as VTS centres. To enhance the performance of VTS, dynamical risk based positioning of tugs has been suggested as a innovative approach. The methodology developed in cooperation with the Norwegian Coastal Administration will help enhance the effectiveness of oil spill prevention from drift grounding accidents by dynamically assessing the risk (for this type of accident) and thus allowing for a risk based positioning of tugs along the coast, placing the tugs where they can be most effective. This paper focuses on the application of the dynamic risk model, with description of an implemented online demonstrator of the model for vessels on the Norwegian coast. It is concluded that the developed decision support system may improve the cost effectiveness of the existing tug program significantly.

Keywords

Dynamic Risk; AIS; Drift grounding; Ship surveillance; VTS; Oil spill. Tug positioning

1. Introduction

Over the last decades, the implementation of ship-borne measures for risk reduction has significantly reduced the number of accidental oil spills from shipping. Today, an important contribution to further risk reduction may be achieved via shore based support systems, such as Vessel Traffic Service (VTS) centres. VTS is the central tool for coordination of vessel traffic monitoring and control. The service enables an operator to interact with the traffic, acting on behalf of an authority, and to respond to situations arising in the VTS area of responsibility. Studies indicate that the risk-reducing effect of a VTS centre is between 20% and 80%, depending on the geography, the traffic density and the resources avail-

able to the VTS (*Danish Maritime Authority & Royal Danish Administration of Navigation and Hydrography, 2002*).

Today, the AIS-transponders aboard the ships enable VTS centres to monitor and track vessels on large stretches of coastline using shore based AIS receivers. AIS is mandated by the International Maritime Organisation (IMO) and included in SOLAS Chapter V (*IMO, 2002a*). From 2002 and onwards, all ships above 300 gross tonnes (GT) carry AIS transponders. The system enables the ships to automatically transmit and receive information (*IMO, 2002b*).

Monitoring far-reaching heavy traffic coastal areas may in turn give the operator an unwieldy number of vessels (e.g. several hundreds) to monitor at any given time. The large number of vessels complicates the process of assisting ships, and directing resources to where they are most useful. In situations where two or more undesirable events occur simultaneously, prioritising can easily become an immense and impossible task for the operator. Because of the need to effectively monitor large number of vessels simultaneously, the VTS centres are looking for means to filter out the unwanted traffic patterns and high risk vessels, in particular hazardous goods traffic (HAZMAT). High risk vessels may then be followed up with special attention and different risk-reducing measures (contingencies) depending on type of vessel, sailing area and traffic pattern. When the global identification and tracking of ships is implemented using Long Range Identification and Tracking (LRIT) technology, the potential for effective monitoring and prioritisation will increase further (*IMO, 2006*).

To enhance the performance of VTS, risk based prioritization has been suggested as a new tool (Eide et al. 2006a). To enable such a prioritization, a new dynamic environmental risk model for drift groundings has been presented (Eide et al. 2007), which could prove a valuable decision support tool for VTS operators. The risk model separates itself from previous models by drawing on available information on dynamic factors and by focusing on the ship's surroundings. It is based on the retrieval of AIS information from each ship, such as position and identity, and the linking of this information to other sources of data. The model estimates the environmental risk of drift grounding accidents in real time and in forecast mode, combining the probability of grounding with potential oil spill impact on the coastline.

The modelling approach incorporates a number of existing operational models (e.g. the ship drift model), available databases (e.g. vulnerability data) and technology platforms (e.g. Automatic Identification System (AIS)), resulting in a risk assessment tool intended for use in improved traffic management (e.g. Vessel Traffic Services (VTS)) (Eide et al 2006b).

The methodology described in this paper (as part of the Norwegian Research Council projects “AIS2010 - Innovative use of AIS” and “FOB - Enhanced monitoring and decision support”) will help enhance the effectiveness of oil spill prevention from drift grounding accidents by dynamically assessing the risk (for this type of accident) for ships along the coast (Figure 1), and thus allowing for a risk based positioning of tugs along the coast, placing the tugs where they can be most effective. Tugs are often used either in an escort capacity (following a moving vessel), or as sentinels (on hold in a given position). The escort function is more effective, but also more expensive (The Glosten Associates, 2004). The described model may assist in bringing the safety effect of the tug close to the escort performance, while keeping the costs at sentinel level, by giving the tug an opportunity to be in the right place at the right time. The proposed risk assessment model may be used as a foundation upon which operational procedures, as outlined in Eide et al. (2006a), may be developed (Figure 2).

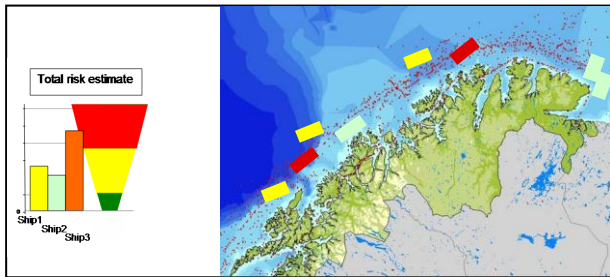


Figure 1: Illustration of risk modelling (left: three selected ships, right: modelling made for 8 ships).

The model has been implemented for testing in a VTS at Vardø in Northern Norway operated by the Norwegian Coastal Administration. This area is of particular interest because of the rapid growth in oil transportation in the arctic and sub-arctic regions of the world, such as in Russian and Norwegian waters.

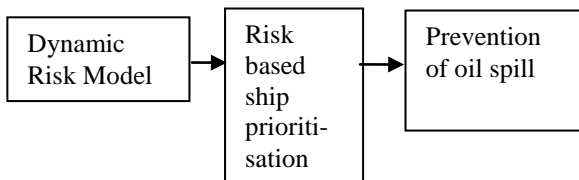


Figure 2: Context of the Dynamic risk model. The current paper describes model which is needed as a the first step to reduce environmental risk.

This paper focuses on the application of the dynamic risk model. The model is presented in section 2, with modelling results presented in section 3. A description of the implemented online demonstrator of the model for vessels on the Norwegian coast is given in section 4. This model effectively enables optimization of the position of the tug, and we illustrate that this will significantly improve the cost effectiveness of the existing tug program. This paper also show that oil spill volumes and clean up cost for drift grounding accidents are higher compared to other accident types (section 5).

2. Dynamic Modelling approach for Drift Grounding

The proposed dynamic model uses input from a wide range of sources, extending beyond previously developed ship prioritisation models, by utilising dynamic information regarding the ship’s surroundings and environment in addition to information regarding the ship itself. The model outline is presented in Figure 3.

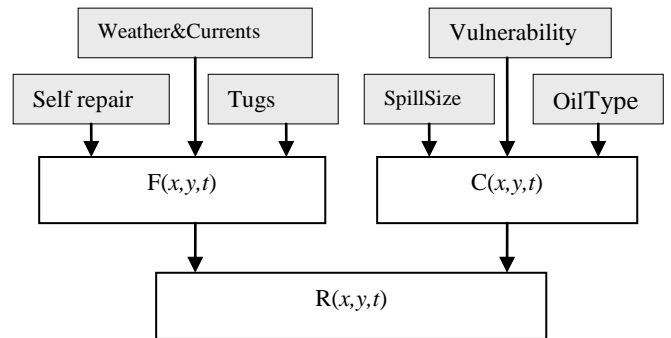


Figure 3: Dynamic drift grounding Risk Model Outline, x and y parameterise ship position, t parameterise time.

In general, the dynamic information regards characteristics of an object or conditions changing over time. This information can be ship position, wind, currents and waves, loading conditions, proximity to land, traffic conditions and available contingency resources. The list goes on, and depends on the type of accident under consideration. The information in this category change over the time (minutes, hours or days), and is used to produce an assessment of the environmental risk level that may change rapidly. A risk model utilising this information will thus produce an estimate of *dynamic risk*. The proposed model can draw upon a vast pool of information, making it possible to asses risk in close to real-time in an accurate manner, and also predict risk exposure ahead of time. The dynamic factors may impact on both the probability of an accident, and on the consequences of the accident. In general the dynamic risk is a function of location (x and y coordinates) and time (t). As risk (R) is defined as frequency (F) times consequence (C), the dependence on location and time may be modelled through one or both of these factors:

$$R = R(x, y, t) = F(x, y, t) \cdot C(x, y, t) \quad (1)$$

In the current context the ship risk, as defined in Equation (1), will vary with both the position (x, y) of the ship as well as with time (t) by modelling both the frequency and the consequence dynamically. Note that the position of the ship is automatically updated and transmitted by AIS.

The type of risk under consideration is the risk of oil spill and subsequent environmental damage. This risk is commonly measured in units of *tonnes of oil spilled per ship year*, referred to in the literature as pollution risk (Lehman & Sørsgård, 2000). However, since the impact of oil spills may vary considerably depending on what, when and where it is spilled, it may be more useful to include some measure on the environmental impact of the oil spill, thus assigning to a risk unit of *oil spill impact per ship year*. This is in the literature referred to as environmental risk (Lehman & Sørsgård, 2000). Though this is a less stringent measure in terms of absolute risk levels, it is convenient for comparison between ships. It is realised that the proposed unit for R is not informative in any context outside of the specific application of the presented model. However, since the objective is to produce a decision support tool to aid in the prioritisation of ships of the coast, the units used need not be applicable outside this scope.

Because of the difficulties involved with presenting the risk of environmental damage in stringently defined and meaningful units, it is proposed to utilise the modelled results on several levels. This means extracting results of the modelling prior to the final result in the risk format *impact per ship year* (i.e. environmental risk). This is illustrated in part in *Table 1* with the inclusion of the *frequency* and *consequence* columns. Moving up the result presentation levels will represent results of increasing modelling detail, and of increasing value to specialised users. However, the increase of level will involve a decrease in generality and firmness of definitions and perhaps also in objectivity, possibility of verification and comparability with statistics and other models. It should be noted that the first level output, which is simply the probability of the drift grounding event excluding all consequence considerations (*Table 1*, column *Frequency*), provides a basis for modelling other risks, such as loss of life or property damage. The probability modelling is universal for all consequences. The second level would be the pollution risk level, measured in *tonnes of oil per ship year*, and would be compatible with use of cost-effectiveness criteria such as the Cost of Averting one Tonne of oil Spill (CATS) criteria (Skjong et al., 2005). Generally, obtaining generic cost information for oil spills which cover a range of oil types and different geographical areas is difficult. The type of oil, the location of the spill, the characteristics of the affected area and spill amount are generally the most important technical factors determining the oil spill cost. New legislation in the past decade may have made historical oil spill data obsolete, as the fleet sailing

today is vastly improved. The cost data that is available shows great variation between spills (Grey (1999), Jean-Hansen (2003), Etkin (1999; 2000; 2005), White and Molloy (2003), and (IOPC Funds, 2006)). Application of oil spill cost data in risk modelling is important, particularly in evaluating design measures for prevention and control of marine oil spills. Better data on oil input to the environment, as well as cost data are needed. The third and final level, environmental risk, which is expressed in terms of *impact per ship year* is appropriate for comparison of individual ships or geographical areas (*Table 1*, column *Risk*).

The information provided to the users of the dynamic risk model should show an overall risk level and details provided in the calculation steps prior to the final risk calculation. Of particular importance are values that show the VTS operator the reason why a risk level is high, indicating which measures to apply in order to decrease the risk. If applied correctly, the additional information may help determine which risk reducing measures will be most effective for each ship.

2.1 Accident Frequency Modelling

Drift grounding occurs when a ship loses its ability to navigate, through loss of steering or propulsion, and is forced onto the shoreline before it is either taken in tow or is repaired. The frequency of drift grounding is modelled to be the product of the frequency of ship drift incidents (F_{drift}) and the probability of grounding given that the ship is adrift ($P_{grounding|drift}$):

$$F(x, y, t) = F_{drift} \cdot P_{grounding|drift}(x, y, t) \quad (2)$$

The failure rates for propulsion and steering are available from the SAFECO project (Hansson & Kiær, 1997). The probability of avoiding grounding, $1 - P(\text{ground}|drift)$, depends on the ship either being able to repair the problem on its own, or receiving assistance from tugs, and ultimately that either of the solutions can be achieved in time to avoid the grounding. The most general way to describe this is with three probability density functions: the “tug response time”-distribution (f_{TRT}), the “time to shore”-distribution (f_{TTS}) and the “self repair time”-distribution (f_{SRT}). The “time to shore” probability density function is modelled in detail using a ship drift model (Sørsgård & Vada, 1998). The distribution is based on 500 simulation runs with small perturbations, and will depend on local currents, weather (wind and waves), proximity to shore and properties of the drifting vessel (e.g. ship type, draft, size, loading condition). The inherent uncertainty in weather prediction and vessel response to its environment will be transferred to the probability density function by perturbations of input data to the ship drift model. Further details are given in Eide et al. (2007).

2.2 Consequence modelling

The environmental consequence of a drift grounding

accident (C) will be modelled in two separate parts. The first part will relate solely to the expected quantity of oil spilled in an accident, i.e. the expected spill size (S). The second part concerns the impact (I) of one tonne of oil on the environment. The consequence model is thus split such as to describe the *quantity* and *quality* of the oil spill separately. Furthermore, bunker spill (subscript b) and cargo spill (subscript c) is modelled separately, with regard to both spill size and spill impact:

$$C = C_c + C_b = S_c \cdot I_c + S_b \cdot I_b = \sum_{i=b,c} S_i \cdot I_i \quad (3)$$

The essentials of this model are provided in the following subsections, while details are given in Eide et al. (2007).

2.2.1 Spill size modelling

The spill size of drift groundings depends on the ship type, size, loading condition and whether the ship is single or double hulled. The expected spill size in the event of an accident, S , is found by combining the probability of an oil spill given an accident $P^{(s)}$ with the expected oil outflow in the event of a spill O . This is modelled for both bunker tanks (b) and cargo tanks (c), which makes the model applicable also to non-tanker vessels and tanker vessels in ballast:

$$S_i = P^{(s)} \cdot O_i \quad \text{for } i = b, c \quad (4)$$

The volume of oil outflow O from cargo and bunker tanks given that there is a spill accident, is modelled as:

$$O_i = \alpha_i \cdot \beta_i \cdot Dwt \quad \text{for } i = b, c \quad (5)$$

where α_i is the expected outflow rate given as a percentage of the tank content volume (depends on accident type), for both cargo and bunker tanks; β_i is the volume of cargo and bunker oil respectively as a percentage of vessel deadweight tonnage Dwt .

2.2.2 Impact modelling

The spill impact (I) per tonne oil depends on the affected area's vulnerability to oil pollution, as well as on the type of oil spilled. For the bunker (b) as well as for cargo (c) spill, the environmental impact factor will then be modelled in two parts: As an environmental sensitivity index (E) and oil type significance index (T):

$$I_i = E \cdot T_i \quad \text{for } i = b, c \quad (6)$$

The first part will incorporate the vulnerability and ecological significance of a selected geographical area, and is independent of oil type. The second part describes the significance of the oil type spilled. Both E and T are modelled as relative indices, i.e. with little regard for the absolute levels. This is practical as the use of the model is the relative comparison of ships, and the absolute level of the values for spill impact is of little importance.

3 Modelling Results for Drift Grounding

3.1 Case description and input data

To illustrate the modelling approach for drift grounding described in Section 2 some modelling example cases are presented. All cases are based on the assumption that a loaded Aframax crude oil tanker of 80,000 Dwt (240 meters in length) is identified through AIS at a position off the Norwegian coast. The propensity for this tanker to falter (the potential risk level, R) is then estimated from Equation (1) under different circumstances. Each set of circumstances is given a case number. For simplicity, not all model variables are altered in these test cases. However, the selected cases are intended to illustrate some central aspects of the model. The different cases are outlined in Table 1. The initial position is left unchanged for all cases. So is the season, which would otherwise impact on the environmental vulnerability. Two weather and ocean current situations resulting in two distinct "time to shore" distributions have been used: one with "fast" drift and one with "slow" drift. Both distributions are based on actual simulations using the operational *ship drift model for Norwegian waters* (Sørgård & Vada, 1998), using real weather and currents data. The time development of the fast drift situation is illustrated in Figure 4. For each of the two weather and ocean current cases two oil types, one heavy and one light, are investigated. Furthermore, two assumed tug positions are used: Kirkenes and Hammerfest, resulting in two distinctly different "tug response time" distributions.

3.2 Results and discussion

The results in Table 1 clearly demonstrate the great variances in potential accident frequency and environmental risk, depending on the circumstances surrounding the drifting vessel. It is evident that the impact of tug position varies with the drift time to shore: in benign weather conditions the risk is negligible when a tug is available in Hammerfest (case 1), while there is a small risk associated with having the tug as far away as Kirkenes (case 2). As the weather worsens, the difference between having a tug in Kirkenes (case 4) and having a tug in Hammerfest (case 5) is a factor 6. Furthermore, the type of oil carried as cargo has a significant impact on the risks. The factor varies from 6 to 9. The greatest difference in risk is the result of weather and currents. The results show that the risks may differ by as much as a factor 45 (case 2 vs. case 6). Table 1 shows that all cases 1 to 4 are generally less critical than cases 5 to 8. This is the weather impact. However, case 5 is less critical than case 4, showing that the combined effects of having a tug close by and carrying light oil can compensate for severe weather conditions. Also, case 6 and 7 show that a favourable tug position can nearly outweigh the effect of carrying heavy oil cargo.

Table 1: Modelling Results. Season: Spring, Initial position of drifting vessel: UTM 33 -7958106 N, 864291 E. The results illustrate change in weather, difference in cargo type and change in tug position Tug position A = Hammerfest, B=Kirkenes.. Unit of risk is impact per ship year.

Wind & Current	Crude Oil Type	Tug position	Case Number	Frequency	Consequence	Risk
Slow drift	Light	A	1	0.0	258	0
		B	2	0.005	258	1
	Heavy	A	3	0.0	1719	0
		B	4	0.005	1719	9
Fast drift	Light	A	5	0.029	258	7
		B	6	0.17	258	45
	Heavy	A	7	0.029	1719	49
		B	8	0.17	1719	299

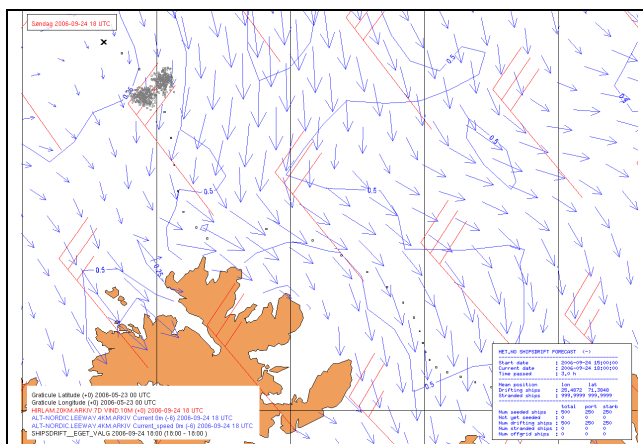


Figure 4: Simulated drift to shore snapshot. 500 simulated vessels are released in position marked x. Figure (a) shows drifting vessels (grey dots) after 3 hours, with currents (blue arrows) and winds (red arrows). In this specific case most of the 500 vessels are grounded after 12 hours (not shown in figure)

Eide et al (2007) discusses the uncertainties related to the model. Based on that discussion, some uncertainty is expected in the estimated risk levels, and a more detailed sensitivity analysis has to be made to quantify the uncertainty. Nevertheless, it is likely that the results are representative as indicators of risks, well suited for the intended use of the model namely relative comparisons of ships and areas (at the same time). Furthermore, it is expected that the use of this novel approach will provide insights into the performance and reliability of the model, and that adjustments should be made based on gained experience.

4 Operational use and visual representation

The results obtained with the proposed model, as shown in the previous section must be used with care. The intended use is decision support, not decision making. Ultimately, all decisions must be made by qualified operators, and all decisions should draw on all available information (Skinner, 2001) and not on any one model

alone. This section describes how the dynamic risk model for drift grounding can be effectively used for decision support.

As of February 2008, an upgraded online demonstration application of the dynamic risk model for drift grounding is available for the project participants (a first version was available in December 2006). Based on the dynamic risk model (Equation (1)) developed by Det Norske Veritas, this demonstrator has been implemented by Christian Michelsen Research, with model and data input from met.no, and AIS data from the Norwegian Coastal Administration. The demonstrator is intended for trial implementation with the Norwegian Coastal Administration, at VTS Vardø.

This tool will be used for optimizing the deployment of the tugs managed by the Coastal Administration for vessels passing along the coast between Lofoten and Vadsø. Here most of the traffic follows the new traffic separation scheme 30 nm from the coast.

In the demonstrator, risk is calculated for tankers (defined as tanker in AIS) inside a defined corridor. If the tanker has hazardous cargo both cargo and bunker is included in spill size modelling, otherwise only bunker is included. At the current position of the vessel, the triangle representing the vessel is coloured by the current risk. The risk is also calculated 9 hours ahead along a predicted route (Figure 5), if the vessel is following the corridor (+/-45 degrees). A rectangle around the triangle shows the vessel coloured by the maximum risk along the route.

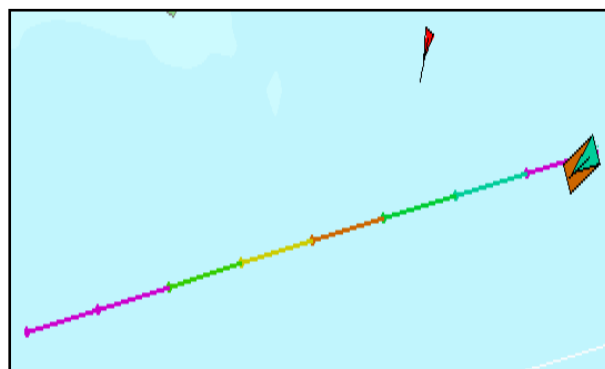


Figure 5 Illustration of the visual representation of the risk, in real time (triangle color) as well as in forecast mode (square color). Prediction of risk along predicted route shown for 9 hours ahead in time. The color coding along the route indicates a heightened level of risk after approximately 4 hours of sailing.

As a predicted route a route with a constant distance to the baseline of the corridor, starting at the vessels current position is used. For each hour ahead, a predicted position is calculated using the current speed over ground. At these position, the probabilities and risk indexes is calculated and at each segment along the route, the segment is colored by this risk (or probability, Figure 6). Both the current and predicted risk is calculated continuously, but not more than each 10th minute

using regularly updated forecast data from met.no.

If only the current risk was to be calculated, a high risk vessel would be spotted too late for any countermeasures to be undertaken. Therefore the risk is predicted for the vessels following the separation scheme several hours ahead, giving the operators ample time to react on a possible upcoming situation.

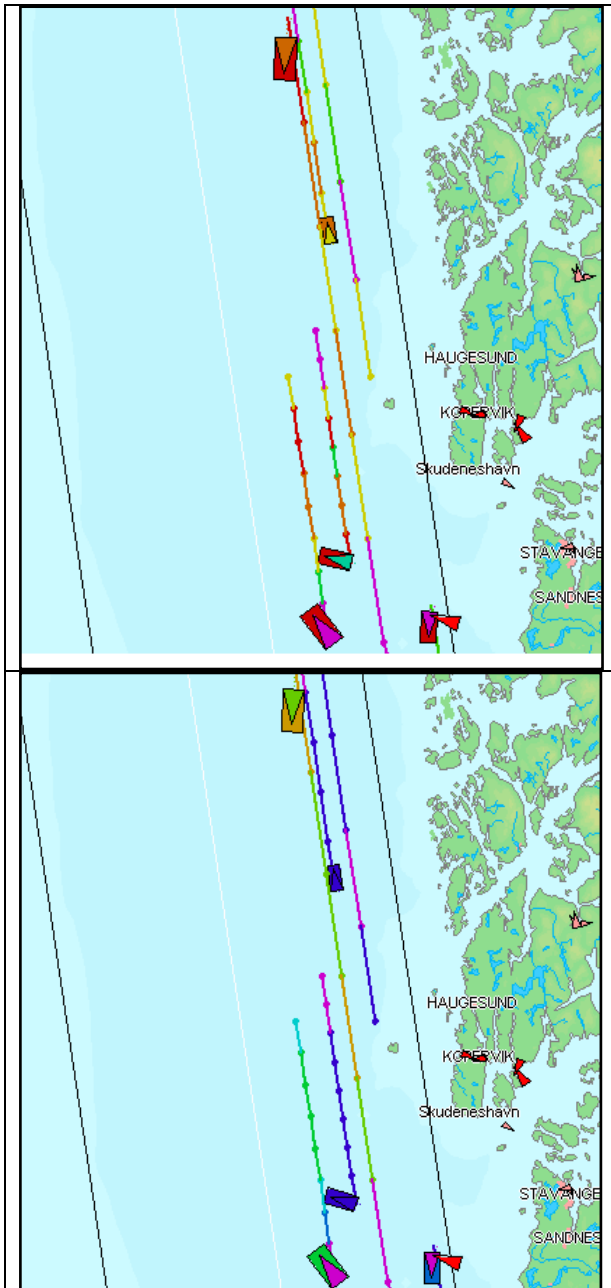


Figure 6 Toggling between displaying the Probability of grounding and the Risk provides added information.

The current implementation of the Dynamic risk model, as described above provides a certain level of decision support for the VTS operator. The operator will be able to assess the risk levels of individual ships into the near future. This allows for adjustments in tug positions.

With limited resources at the VTS operators disposal, these hours of foresight provides good indications and premises for placing resources in optimal positions. This is of value not only in a contingency perspective, but also financially as there is a potential for allowing the tugs to be more stationary, provided that they are placed strategically.

However, more can (and should) be done to further utilize the potential for decision support inherent in the dynamic risk model. Statistics and experience with the use of the model should be aggregated and provide input in the further development of an effective, operational decision support tool. Also, links with the European maritime safety tool SafeSeaNet (*The Norwegian Coastal Administration, 2005*) should be established to optimize use, by improving the possibilities for risk categorization (cargo, passengers/crew, security etc.)

An important aspect for future development is simulating of the effects of moving tugs and other resources. In other words, to let the VTS operators see the effect of changing the position of a tug. The tool should be able to assess these effects not only on a single ship, but the effects for all ships in a region. **Figure 7** is an illustrative example of risk profile over time for two ships (red lines). The green line illustrates an alternative risk profile, when deployment of measures is available. The illustrations show the challenges need to be considered when re-positioning tugs.

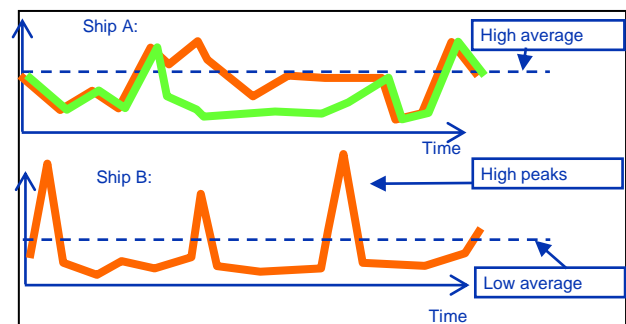


Figure 7: Illustrative example. Risk profile over time for two ships (red lines). Alternative risk profile if deployment of measures (green line).

5 Cleanup costs for Norwegian waters

Quantitative risk assessments make it possible to evaluate the cost effectiveness of different risk reducing measures (*Skjong et al., 2005*). Risk assessments for ships generated over time (months or years) may be aggregated to provide a periodic risk picture covering selected areas (*Thevik et al., 2001*). This in turn will provide decision makers with a tool to evaluate risk reducing measures of a permanent nature against each other by identifying areas of high risk exposure and subsequently evaluating the costs and effects of available measures (*Harrald et al., 1997*). Such permanent measures might include positioning of permanent tug stations, oil spill emergency response units and adjustment of shipping lanes.

Ship traffic surveillance of the sort proposed in this paper is a risk reducing measure which in itself could be analysed with respect to cost effectiveness. This section provides some indications to this effect.

Oil spill clean up cost data and important factors for determination of costs have been reported by i.a. ITOPF¹, Grey (1999), Jean-Hansen (2003), Etkin (1999; 2000; 2005), White and Molloy (2003), and (IOPC Funds, 2006). Most of these studies have been reviewed in Vanem et al (2007a) and the average cost of one tonne of oil spilled varies from 667 US\$/tonne to 180 000 USD/tonne. Etkin (2000) reports that the average cost per tonne of oil spilt varies significantly between regions, with average estimates from 1000 USD/tonne in the Middle East, to 33 000 USD/tonne in Asia. Etkin reports that near-shore spills and in-port spills are 4-5 times as expensive to clean up as offshore spills. Responses to spills of heavy fuels are more than ten times as expensive as spill responses for lighter crudes and diesel fuels. Spill responses for spills less than 30 tonnes are more than ten times as expensive, on a per-unit basis, as for spills of 300 tonnes.

Jean-Hansen (2003) reported expected clean up cost as a function of oil spill size for tankers operating in Norwegian waters. Results from this study have been converted to USD² and are reproduced in Fig. 4, indicating expected cleanup costs of approximately USD 14,000 per tonne. Table 2 illustrates large differences in oil outflow and cost for the different accident types. Drift grounding have the largest oil outflow and costs. Table 3 indicates some 30,000 tonnes of oil outflow for drift grounding accidents on average, representing about 500 million USD in clean up cost if it occurs on the Norwegian coast, as found by combined with the regression in Figure 8.

However, oil spill data, and especially cost data, are scarce and to some extent outdated. New legislation in the past decade may have made historical oil spill data obsolete as the fleet sailing today is vastly improved. The data on spill volumes reported by the SAFECO project (SAFECO, 1997; SAFECO, 1998; SAFECO II, 1999) and the MEHRA project (MEHRA, 2006) are not necessarily representative for today's accident scenarios. New data indicates that the long, historical time series used for calculating oil outflow for crude oil tankers in SAFECO and other sources is outdated. The number of spill incidents is dropping, and so is the volume of spills (ITOPF, 2007). One of the main reasons for this improvement are thought to be the double-hull requirement. The IMO requirements of MARPOL Regulation 13F, as well as other legislation (such as the Oil Pollution Act of 1990), are making single hull tankers obsolete. The share of single hull tankers in the crude oil tanker fleet above 10 000 GT was 24% in 2004 (LRF, 2005), while the share of single hull vessels in the

world tanker fleet was 96% in 1990 and 90% in 1994 (National Academy Press, 1998), indicating a rapid decrease in single hull vessels

Table 2: Average clean-up and environmental costs (Lehmann and Sørsgård, 2000). Global figures.

Accident type	Clean-up costs (mill \$)	Environ. costs (mill \$)
Inter-ship collision	2.2	4.8
Powered Grounding	4.2	10
Drift Grounding	7	18
Fire & Explosion	7	18
Structural Failure	3.7	9

Table 3: Average amount (in tonnes) of oil spilt per oil spill accident given accident type (Lehmann and Sørsgård, 2000). Global figures.

Accident type	Cargo oil
Inter-ship collision	3,000
Powered Grounding	7,000
Drift Grounding	30,000
Fire & Explosion	20,000
Structural Failure	10,000
All accident types	8,000

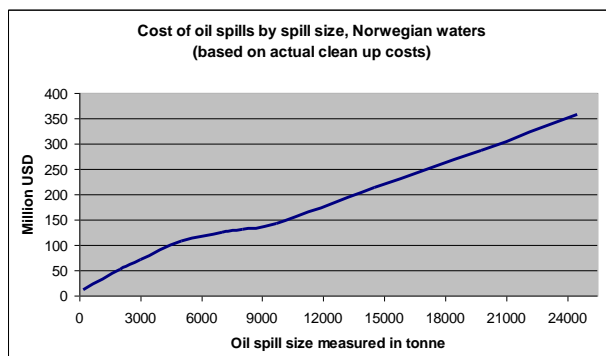


Figure 8: Cleanup costs for Norwegian waters (Vanem et al 2007a)

The estimate of 500 million US dollars in clean up cost could be higher considering the fact that that near-shore spills are 4-5 times as expensive to clean up Etkin (2000) as offshore spills (drift grounding occur in coastal zones). In addition, environmental cost needs to be added. Jean-Hansen (2003) reports that the environmental damage cost is almost 2 times as high as the cost of rescue and clean up operations in Norwegian waters. The study of Lehman & Sørsgård (2000) also indicates that the environmental damage cost is higher than clean up cost

Oil type is also an important variable, as illustrated in Table 4. The table shows an example of how much oil can be expected to reach shore, given that all conditions but oil type is kept constant. Lighter oils will evaporate and disperse more easily, hence reducing the need for cleanup. For the heavy oils, in this specific example,

¹ Available online at: <http://www.itopf.com/costs.html>

² 1 USD = 7 NOK was assumed

the stranded volume is eight times the volume for the light condensate. This clearly indicates the challenges, when estimating the clean up and environmental cost of a drift grounding accident.

Table 4: Percentage of total spill size stranded for different oil types, given a 20 000 m³ spill at a specific location on the Norwegian coast. Fate of oil slick simulated using Monte Carlo methods on hind cast data (Eide et al 2007).

Oil type category	Percentage of initial spill stranded
Light condensate	5%
Medium crude	20%
Heavy crude oil*	40%

*) including bunker oils

Because of the potentially disastrous consequences of a drift grounding oil spill accident, significant resources have been allocated to preventing them. On the coast of Northern Norway, designated tugboats patrol the area to assist drifting ships. Typically, one such tugboat has an annual cost of more than 6 million EUR. As the cost of operating these vessels are significant, maximizing the effect of these costly resources is thus additional motivation for developing support tools, such as the one described here. Based on the above it is suggested that the decision support system under development may improve significantly the cost effectiveness of the existing tug program.

6 Conclusion

The results of this study indicate that the model accounts for the main features defining the risk of a drifting ship situation in the north of Norway, and effectively separates potentially high risk and low risk situations. The results clearly shows the great difference between “good” and “bad” weather situations (factor 45), i.e. winds blowing towards the shore or from the shore. It is clear that two ships sailing along the coast at the same time may very well experience very different weather conditions, and thus pose very different risks to the environment. Not only may the winds have different directions and force, but due to the curving nature of the coastline, the same westerly wind may be blowing from the shore in the east, and towards shore in the west. The same applies to ocean currents. Also, a huge impact is observed from having tugs positioned in the right place at the right time, which is important to assist ships in distress situations, and it is noted that this effect is weather-dependent.

In conclusion, the proposed dynamic risk model facilitates risk based ship traffic monitoring and resource management. The dynamic risk model is a decision support tool, aiding in the prioritisation of individual ships, and by extension, the prioritisation of geographical areas. Though only crude oil tankers are considered in detail, the methodology presented is generic. The

model gives the opportunity to assess the current risk level as well as a forecasted risk level for each ship (and geographical region), based on a wide range of data sources (e.g. AIS and met-ocean data).

The developed demonstrator facilitates risk based decision support at a certain level. However, to harness the full potential of the dynamic risk model approach, further development of the decision support tool is needed. Furthermore, considering the typical cost of drift grounding accidents with oil spill and the high cost of operating standby tugs the model under development shows great potential for cost effectiveness.

7 Acknowledgments

The preparation of this paper was co-funded by the Norwegian Research Council (contract no. 180175/I40). The authors would like to acknowledge Tore Longva of DNV for improving the paper.

8 References

- Danish Maritime Authority & Royal Danish Administration of Navigation and Hydrography (DMA&RDANH), 2002. Risk Analysis of Navigational Safety in Danish Waters. Danish Maritime Authority and Royal Danish Administration of Navigation and Hydrography. Report no. P-054380-2, 2002. Available online at: <http://soefart.inforce.dk/graphics/Synkron-Library/Sofartsstyrelsen/Publikationer/Summary1.pdf>
- Eide M, Endresen Ø, Breivik Ø, Brude O W, Ellingsen I H, Røang K, Hauge J, Brett P O, 2007. Prevention of oil spill from shipping by modelling of dynamic risk. Marine Pollution Bulletin, Vol 54 Issue 10, October 2007, Pages 1619-1633. doi:10.1016/j.marpolbul.2007.06.013
- Eide M, Endresen Ø, Brett P O, Ervik J L, Røang K, 2006a. Intelligent ship traffic monitoring for oil spill prevention: Risk based decision support building on AIS. Marine Pollution Bulletin Volume 54, Issue 2, February 2007, Pages 145-148. doi:10.1016/j.marpolbul.2006.11.004
- Eide, M., Endresen, Ø., Soma, T., Brett, P. O., 2006b. Risk Based Ship Prioritization. DNV report no. 2006-0435. Høvik, Norway.
- Etkin D. & Welch J. (2005), Development of the Oil Spill Response Cost-Effectiveness Analytical Tool, Environmental Research Consulting, Cortlandt Manor, New York, USA. http://www.environmental-research.com/erc_papers/ERC_paper_7.pdf
- Etkin, D. S. (1999). Estimated Clean up Costs for Oil Spill, Proc. 1999 International Oil Spill Conference, 1999.
- Etkin, D.S. (2000). Worldwide Analysis of Marine Oil Spill Cleanup Cost Factors, Presented at: Arctic and Marine Oilspill Program Technical Seminar.

- Grey, C. (1999). "The Cost of Oil Spills from tankers: An analysis of IOPC Fund Incidents", Proc. 1999 International Oil Spill Conference, 1999.
- Hansson, L.H., Kiær, E., 1997. Technical Failures System Criticality Ranking. SAFECO WP II.6, Report no. 233509.00.01.
- Harrald, J. R., Mazzuchi, T. A., Merrick, J., Spahn, J. and Van Dorp, R., 1997. System Simulation: A risk management tool for Prince William Sound. Proceedings of 1997 International Oil Spill Conference. <http://www.itopf.org/information%2Dservices/data%2Dand%2Dstatistics/statistics/index.htm>
- International Maritime Organisation (IMO), 2002a. International Convention for the Safety of Life at Sea (SOLAS). Available at; http://www.imo.org/Conventions/contents.asp?topic_id=257&doc_id=647#9
- International Maritime Organisation (IMO), 2002b. AIS-topic webpage: http://www.imo.org/Safety/mainframe.asp?topic_id=754, accessed September 2006
- International Maritime Organisation (IMO), 2006. Measures to Enhance Maritime Security, Long range Identification and tracking of ships, MSC81/WP.5/Add.1, 18 May.
- International oil pollution compensation funds (IOPC Funds) (2006). Annual Report 2006, (report on the activities of the international oil pollution compensation funds in 2006), data provided in ANNEX XXIII (1971 FUND), ANNEX XXII(1992 FUND), <http://www.iopcfund.org/>
- International Tanker Owners Pollution Federation (ITOPF), 2005. ITOPF Technical Information Paper: Fate of Marine Oil Spills. Available at <http://www.itopf.com/tip2.pdf>
- International Tanker Owners Pollution Federation (ITOPF), 2007. Oil Tanker spill statistics. Available at www.itopf.com/stats.html
- ITOPF (International Tanker Owners Pollution Federation) (2007). Oil Tanker spill statistics.
- Jean-Hansen, V. (2003). Skipstrafikken i området Lofoten – Barentshavet. TØI rapport 644/2003. ISBN: 82-480-0341-8.
- Lehmann, M. P. and Sjørgård, E., 2000. Consequence Model for Ship Accidents. ESREL 2000, SARS and SRA-Europe Annual Conference. Edinburgh, UK. 17 May 2000.
- Lloyds Register Fairplay (LRF) (2005). The World Fleet database for 2004, provided by Lloyds', UK, May 2005.
- Lloyds Register Fairplay (LRF) 2005b. The World Fleet of oil tankers, 1998-2004. Provided by Lloyds', UK.
- National Academy Press (1998). Double-hull Tanker Legislation, An assessment of the oil pollution Act of 1990, Commission on Engineering and Technical Systems, National Research Council, Washington, D.C., 1998. <http://darwin.nap.edu/books/0309063701/html/124.html>
- National Academy Press, 1998. Double-hull Tanker Legislation, An assessment of the oil pollution Act of 1990. Commission on Engineering and Technical Systems, National Research Council, Washington, D.C. <http://darwin.nap.edu/books/0309063701/html/124.html>
- SAFECO (Safety of Shipping in Coastal Waters) (1997). Demonstration of risk analysis techniques for ship transportation in European waters, WP III.1.2-3, DNV rep. no. 98-2021.
- SAFECO (Safety of Shipping in Coastal Waters) (1998). Statistical analysis of ship incidents, WP III.2.rapport nr 97-2039.
- SAFECO II (Safety of Shipping in Coastal Waters II) (1999), Data on consequences following ship accidents, WP III.3, D22B, DNV rep. no. 99-2031.
- Skinner, D. C., 2001. Introduction to Decision Analysis. Second edition. Probabilistic Publishing, USA. ISBN 0-9647938-3-0
- Skjong, R., Vanem E. and Endresen, Ø., 2005. Risk Evaluation Criteria. Ongoing EU project SAFEDOR Deliverable 4.5.2. www.safedor.org
- The Glosten Associates, 2004. Study of Tug Escorts in Puget Sound. Prepared for State of Washington, Department of Ecology, Lacey, Washington.
- The MEHRA-project (2006). Identification of Marine Environmental High Risk Areas (MEHRAs) in the UK, Department for Environment, Food & Rural Affairs, <http://www.defra.gov.uk/environment/consult/mehra/>, accessed 2006.
- The Norwegian Coastal Administration, 2005. Safe-SeaNet Information. Available at: <http://www.kystverket.no/default.aspx?aid=9030959> (In Norwegian)
- The Norwegian Coastal Administration, 2005. Safe-SeaNet Information. Available at: <http://www.kystverket.no/default.aspx?aid=9030959> (In Norwegian)
- Thevik, H. J., Sjørgård, E. and Fowler, T., 2001. A method for assessing the risk of sea transportation: Numerical examples for the Oslofjord. Proceedings of ESREL 2001.
- Vanem, Endresen & Skjong (2007a). CATS – Cost-effectiveness in Designing for Oil Spill Prevention. 10th International Symposium on Practical Design of Ships and Other Floating Structures, Houston, Texas, United States of America.
- White, I. C. and Molloy, F. (2003). Factors that Deter-

mine the Cost of Oil Spills, proc. International Oil Spill Conference 2003.