A method for assessing the risk of sea transportation: Numerical examples for the Oslofjord

Håvard J. Thevik*, Eirik Sørgård†, and Tim Fowler‡

* Veritasveien 1, N-1322 Høvik, Norway. Havard.Thevik@dnv.com
† Veritasveien 1, N-1322 Høvik, Norway. Eirik.Sorgaard@dnv.com
‡ Palace House, 3 Cathedral Street, London SE19DE, UK. Tim.Fowler@dnv.com

ABSTRACT

The objective of the work described in this paper is to establish a model for risk assessment of sea transportation in the inner part of the Oslofjord. Inherent in ship transportation is the risk of marine accidents. Such accidents can have severe consequences. In order to address the need for an assessment tool for the risk associated with marine accidents, a “Marine Accident Risk Calculation System” (MARCS) has been developed by Det Norske Veritas (DNV). MARCS uses a statistical approach to calculate the frequency and consequence of marine accidents. The MARCS predictions for accident frequencies in the Oslofjord have been compared with historical data. The historical data is based on recordings from the Norwegian DAMA database. This database was developed and maintained by the Norwegian Directorate of Shipping and Navigation, the Norwegian Coast Administration, and DNV. The DAMA database contains a complete recording of all incidents related to marine accidents in Norwegian waters in the period from 1991 to 1996. In total, 63 incidents were reported for the inner part of the Oslofjord in this period that corresponds to the accident types accounted for in MARCS. It is found that MARCS qualitatively, and largely quantitatively, is able to reproduce historical accident frequencies. In conclusion, the results show that MARCS is well suited to analyse risk associated with sea transport close to the coast and in narrow waters such as the Oslofjord.

1. INTRODUCTION

Inherent in ship transportation is the risk of marine accidents. Such accidents can have severe consequences. Lives can be lost, environment damaged, e.g. due to oil spills, and property damaged or lost. Thus, it is of interest to understand the mechanisms that contribute to marine accidents. Quantitative knowledge of the factors contributing to accidents makes it possible to predict future risks and to identify points of improvement in order to increase safety and efficiency of sea transportation.

In order to address the need for an assessment tool for the risk associated with marine accidents, a “Marine Accident Risk Calculation System” (MARCS) have been developed by DNV, cf. Ref. [1]. MARCS uses a statistical approach to calculate the frequency and consequence of marine accidents. The program system has successfully been used as an analysis tool in several projects, see for example Ref. [2] and the report “Prince William Sound, Alaska, Risk Assessment Study – Final Report”, Ref. [3].

MARCS uses environmental and coast line data, traffic image and performance factors internal and external to the ship to calculate the frequency and consequence of the following accident types: Ship-ship collisions, powered groundings (groundings which occur when the ship has the ability to navigate safely yet goes aground), drift groundings (groundings as a result of propulsion or steering system breakdown), structural failure/foundering, and fire/explosion whilst underway.

The purpose of the work reported here is to develop a model for risk assessment of the ship transportation in the Oslofjord. The development will rely on the risk assessment
methodology employed in the SAFECO project, cf. Ref. [4] and Ref. [5]. This implies that MARCS will be used to calculate the risk of marine accidents. An important issue in the project is to answer if MARCS, in its present state, can adequately model the risk of ship transport in narrow waters as the Oslofjord. It should be noted that in the present work only MARCS predictions for accident frequencies, and not consequences such as oil spill and life’s lost, will be presented and compared to historical accident data.

In Section 3, the concepts of the risk assessment methodology are summarized. The definition of a “base case” for analyzing marine accident risks in the Oslofjord by means of MARCS is explained in Section 4. Historical accident data are presented and compared with the corresponding accident frequencies predicted by MARCS in Section 5. In Section 6, the sensitivity of the MARCS predictions upon variations in the input parameters is investigated.

2. RISK ASSESSMENT METHODOLOGY

The modeling approach employed in MARCS is described in detail in Ref. [1]. Here, only a brief review of the concepts within MARCS will be given.

MARCS accounts for five types of accidents. The accident types are modelled separately within MARCS, which assumes that trading marine traffic follows relatively well defined shipping lanes that have a characteristic lane width, traffic frequency (voyages per year) and lateral distribution. The models associated with each of the accident types are:

1. The **Collision Model** calculates the frequency of inter-ship powered collisions at a given geographical location. This model estimates the frequency of close quarters encounters and applies a probability of a collision for each encounter, to give the collision frequency. This probability is related to a number of factors including the visibility conditions and the extent of internal and external vigilance.

2. The **Powered Grounding Model** calculates the frequency of powered groundings that result from marine traffic lanes located in close proximity to the shoreline or shallow water. The main powered grounding mode included in the model is powered grounding due to failure to make a critical course change. The failure probability is related to a number of factors including the visibility conditions and the extent of internal and external vigilance.

3. The **Drift Grounding Model** assumes that drift grounding occurs when a ship loses the ability to navigate, due to steering or engine failure, and is subsequently forced onto the shoreline through the action of wind or current. A frequency factor obtained from fault tree analysis, is used to determine the frequency of propulsion and steering system breakdown. The model includes probabilities for self repair and rescue by anchoring or tug assistance within given time limits.

4. The **Structural Failure Model** calculates the frequency of such accidents whilst underway by applying an accident frequency factor per vessel hour at sea. The frequency factor applied takes account of the severity of the seastate conditions at the current location.

5. The **Fire and Explosion Model** assumes that the frequency of such an accident is controlled by the number of vessel miles travelled. A frequency factor is derived from the historical data.
Frequency of accidents

Each accident model within MARCS calculates the accident frequencies as the product of two terms, as illustrated by the following equation:

\[
\text{Accidents per Area and per Year} = \text{Number of critical situations per Area and per Year} \times \text{Probability of accident per Critical situation}
\]

What is considered as a critical situation for each of the accident types is described below:

- For collisions, the critical situation is defined as when two ships come to close quarters; passing within half a nautical mile of each other (encounter situation).
- For powered grounding, the dominant critical situation is defined as when a vessel track results in a way-point within 20 minutes of a landfall, such that if a course change is not made a powered grounding results.
- For drift grounding the critical situation is defined as the number of ship hours spent within 50 nautical miles of the shoreline multiplied by the probability that the wind blows towards the shoreline.
- The critical situation for structural failure is defined as the number of ship-hours of exposure to certain defined sea-state conditions.
- For fire and explosion, analysis indicates that the likelihood of a fire/explosion onboard a vessel whilst underway is independent of the situation external to the ship. Thus the critical situation of importance is the number of ship hours of exposure.

The number of critical situations per area per year is derived from the traffic image and other data that describes the environment or setting in which the ship trades.

The probability of an accident per critical situation is derived from fault tree analysis and historical statistics.

3. MARCS MODELING

In this section, a so-called base case is defined. The base case describes the current situation in the Oslofjord, and will be used as a reference case in subsequent parameter studies. The study area is defined by the following window: 58°30'N to 60°N and 8°E to 12°E. The region under consideration is displayed in Figure 1. There are four categories of data that must be specified: environmental data, marine traffic data, external operational data, and internal operational data.

The environmental data describes the location of geographical features (land, offshore structures etc.) and meteorological data (visibility, seastate and windrose data). The data are based on meteorological observations at Fornebu (inner part of the Oslofjord) and Færder (outer part of the Oslofjord) in the period 1961 – 1990 received from the Norwegian Meteorological Institute. The positions of the observations for the inner and outer part of the Oslofjord are 59°53.56N, 10°36.95E and 59°01.60N, 10°31.80E, respectively.

The marine traffic data describes the movements of oil tankers, bulk carriers, general cargo vessels, ferries and offshore support vessels in the three case study areas. All of these data types are represented using lane data structures. These lane data structures are comprised of two data sets, namely the volume of vessels using the shipping lanes, in terms of the frequency of voyages per year and the speed of each vessel type. Marine traffic data for the case study areas are taken from a study performed by Dovre Safetec, Ref. [6].
The MARCS model describes external operating data in terms of the location of Vessel Traffic Management Systems (VTS), “anchor save lines”, and tugs. The implementation of these data in MARCS is described in Ref. [4]. In the present study, any positive effects of VTS-systems are neglected, nor is any drift grounding saves due to tugs accounted for. Furthermore, at some locations in the Oslofjord the sea bottom is such that there is a probability to avoid drift grounding by using the anchor. This have been reflected in the modeling of the base case.

Within the present study, the internal operating data covers the following types of data:
* probability of accidents given the number of critical situations (relevant for all accident types)
* self-repair time distribution (relevant for drift groundings only)

A thorough discussion pertaining the above data can be found in Ref. [5].

4. HISTORICAL ACCIDENT DATA FOR THE OSLOFJORD
DAMA is a database for accidents at sea which was developed and maintained by the Norwegian Directorate of Shipping and Navigation (Sjøfartsdirektoratet), the Norwegian Coast Administration and Det Norske Veritas. DAMA contains details of all reported incidents involving Norwegian merchant ships, independent of the actual position of the incidents. Foreign merchant ships that have been involved in incidents in Norwegian waters, are also included (as from 1991). Both serious incidents and incidents where the ship was not damaged are included as long as they meet the requirements of being incidents that have to be reported to the Norwegian authorities, whereas MARCS is calibrated to calculate the frequency of “serious” accidents, where serious has the meaning defined by Lloyds Casualty database.

The 63 incidents referred to above could then be summarised as shown in Table 1. It is also interesting to compare the accident frequencies for the Oslofjord with corresponding numbers for other waters. A comparison with accident data for the North Sea (NS) area and estimates for accidents world wide (WW) is shown in Table 2. The accident frequencies for the Oslofjord have been calculated in a similar way as the data for the North Sea area (discussed in Ref. [5]). Based on traffic data in Ref. [6], the ship miles per year could be extracted. Moreover, it is assumed that the representative period for registrations in the DAMA database is five and a half year.

When comparing the historical accident data of the Oslofjord with corresponding data from the North Sea area and world-wide data (cf. Table 2), it is important to note that the total number of accidents within the Oslofjord area is small. For instance, for drift grounding, fire and explosion, and structural failure, there are only a few accidents over the five and half year period. Since the data are scarce, one should be very careful with drawing to firm conclusions based on the Oslofjord data. However, some comments can be made:
- There seems to be more collisions in the Oslofjord that in the other areas. This can be explained with a relatively high traffic in narrow waters, especially in the inner part of the fjord.
- Powered groundings are more frequent in the Oslofjord compared to the other areas. This is to be expected since the ships travel closer to the shore line in the Oslofjord area than in the North Sea area and world-wide. However, it should also be noted that the accidents in the DAMA database are incidents that have been reported to Norwegian authorities. The
Figure 1: Overview of the study area. The displayed region stretches from: 58°30’N to 60°N and 9°E to 11°20’E.

Table 1: Historical accident data for the Oslofjord based on the data in DAMA from 1991 to 1996.

<table>
<thead>
<tr>
<th>Ship Type</th>
<th>Collision</th>
<th>Powered Grounding</th>
<th>Drift Grounding</th>
<th>Fire and Explosion</th>
<th>Structural Failure</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanker</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Bulk Carrier</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>General Cargo</td>
<td>2</td>
<td>17</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>Ferry</td>
<td>12</td>
<td>18</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>43</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>63</td>
</tr>
</tbody>
</table>

Table 2: Historical accident frequencies (number of accidents per 1000 shipyears) for the Oslofjord (OF), the North Sea area (NS), and worldwide (WW). Data for the North Sea area and world-wide estimates are taken from Table 8.2.1 in Ref. [5].

<table>
<thead>
<tr>
<th>Ship Type</th>
<th>Collision</th>
<th>Powered Grounding</th>
<th>Drift Grounding</th>
<th>Fire and Explosion</th>
<th>Structural Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OF</td>
<td>NS</td>
<td>WW</td>
<td>OF</td>
<td>NS</td>
</tr>
<tr>
<td>Tanker</td>
<td>0</td>
<td>23.7</td>
<td>1.9</td>
<td>196</td>
<td>9.7</td>
</tr>
<tr>
<td>Bulk</td>
<td>0</td>
<td>42.3</td>
<td>2.4</td>
<td>1303</td>
<td>9.0</td>
</tr>
<tr>
<td>General Cargo</td>
<td>31.3</td>
<td>23.3</td>
<td>2.1</td>
<td>266</td>
<td>9.6</td>
</tr>
<tr>
<td>Ferry</td>
<td>212</td>
<td>37.0</td>
<td>9.3</td>
<td>319</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Oslo
accident data for the North Sea and world-wide are so-called serious accidents recorded in the causality database from Lloyds Maritime Information Services (LMIS). It is expected that the DAMA database contains relative more accidents than the LMIS database. It is believed that the main reason for the very large powered grounding frequencies observed in the Oslofjord relative to the North Sea area as well as world wide (cf. Table 2), is related to the fact that the DAMA database contains incidents that not necessarily would have been reported in the LMIS database. Another reason for the seemingly large, historical accident frequencies in the Oslofjord might be that the ship traffic has been underestimated for the Oslofjord region when calculating the figures displayed in Table 2.

5. COMPARISON BETWEEN HISTORICAL ACCIDENT DATA AND MARCS PREDICTIONS

The MARCS calculations based on the data presented in Section 3 are summarised and compared with historical data in Table 4. Furthermore, the ratio between the MARCS predictions and the historical accident frequencies are displayed in Table 5.

As commented in the previous subsection, there are rather few accidents within the five and half year period that is the basis for the historical accident frequencies. This is especially true for structural failures, for which there are no reported incidents, and for fire and explosions and drift groundings, for which there are only three incidents each. When comparing the MARCS prediction with data from DAMA, one should therefore bear in mind that the limited historical data have a large variance. Furthermore, internal parameters in the MARCS software for fire and explosions and structural failure correspond to world-wide serious accidents frequencies as recorded in LMIS. As discussed in the previous subsection, this will likely introduce a discrepancy between MARCS predictions and the accident frequencies obtained from DAMA.

Qualitatively, and largely quantitatively, MARCS is able to reproduce the historically observed accident frequencies. Concerning the quantitative correspondence between the accident frequency predictions and the historical data, the following comments can be made:

- **Collisions**: The predicted number of collisions corresponds well to the observed number of accidents. This good agreement is even better than the agreement obtained between predicted and historical collision frequencies in the study of the North Sea area, Ref. [5].

- **Powered groundings**: For all vessel types except bulk carriers, there is a significant over-prediction of powered grounding accidents compared to historical data. For ferries, MARCS predicts more than ten times the observed number of accidents. It should be noted that a large over-prediction for ferries also was obtained in the North Sea study, Ref. [5]. It is believed that this is related to the fact that ferries have very good manoeuvrability capabilities and often have a crew of three persons on the bridge that is alert and familiar with the coastal areas. These accident-reducing measures are, at present, not properly accounted for in the modelling.

- **Drift groundings**: Drift grounding predictions are higher than observed frequencies. For general cargo vessels, MARCS calculates the drift groundings to be more than 26 times the reported number of drift groundings. This large discrepancy is probably due to an erroneous (too conservative) self-repair time distribution and a too high machinery breakdown frequency. Furthermore, it should be noted that the probability of rescue by tugs is neglected in the present study. Moreover, the modelling of anchor save and the specification/position of the anchor save lines are uncertain, cf. the discussion in Ref. [5]. Notice, however, that ferry predictions correspond well to observed data, which most likely is related to the fact that the machinery breakdown probability has been set
significantly lower for ferries compared to the other vessel types, as it should be since many ferries have partial redundancy in their mechanical systems.

Table 4: Historical accident data and MARCS predictions (accidents per year).

<table>
<thead>
<tr>
<th></th>
<th>Collision</th>
<th>Powered Grounding</th>
<th>Drift Grounding</th>
<th>Fire and explosion</th>
<th>Structural failure</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanker</td>
<td>0</td>
<td>0.5</td>
<td>0</td>
<td>0.2</td>
<td>0</td>
<td>0.7</td>
</tr>
<tr>
<td>Bulk Carrier</td>
<td>0</td>
<td>0.9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.9</td>
</tr>
<tr>
<td>General Cargo</td>
<td>0.4</td>
<td>3.1</td>
<td>0.4</td>
<td>0</td>
<td>0</td>
<td>3.9</td>
</tr>
<tr>
<td>Ferry</td>
<td>2.2</td>
<td>3.3</td>
<td>0.2</td>
<td>0.4</td>
<td>0</td>
<td>6.1</td>
</tr>
<tr>
<td>Total</td>
<td>2.6</td>
<td>7.8</td>
<td>0.6</td>
<td>0.6</td>
<td>0</td>
<td>11.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Collision</th>
<th>Powered Grounding</th>
<th>Drift Grounding</th>
<th>Fire and explosion</th>
<th>Structural failure</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanker</td>
<td>0.1</td>
<td>2.2</td>
<td>1.4</td>
<td>0.007</td>
<td>0.004</td>
<td>3.8</td>
</tr>
<tr>
<td>Bulk Carrier</td>
<td>0.02</td>
<td>0.5</td>
<td>0.3</td>
<td>0.002</td>
<td>0.002</td>
<td>0.8</td>
</tr>
<tr>
<td>General Cargo</td>
<td>0.6</td>
<td>16.1</td>
<td>10.5</td>
<td>0.02</td>
<td>0.05</td>
<td>27.2</td>
</tr>
<tr>
<td>Ferry</td>
<td>1.3</td>
<td>37.3</td>
<td>0.3</td>
<td>0.02</td>
<td>0.02</td>
<td>38.9</td>
</tr>
<tr>
<td>Total</td>
<td>2.0</td>
<td>56.1</td>
<td>12.5</td>
<td>0.05</td>
<td>0.07</td>
<td>70.7</td>
</tr>
</tbody>
</table>

Table 5: Ratio of predicted to historical accident frequencies.

<table>
<thead>
<tr>
<th></th>
<th>Collision</th>
<th>Powered Grounding</th>
<th>Drift Grounding</th>
<th>Fire and explosion</th>
<th>Structural failure</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanker</td>
<td>N.A.</td>
<td>4.4</td>
<td>N.A</td>
<td>0.04</td>
<td>N.A.</td>
<td>5.3</td>
</tr>
<tr>
<td>Bulk Carrier</td>
<td>N.A.</td>
<td>0.6</td>
<td>N.A</td>
<td>N.A</td>
<td>N.A.</td>
<td>0.9</td>
</tr>
<tr>
<td>General Cargo</td>
<td>1.5</td>
<td>5.2</td>
<td>26.3</td>
<td>N.A.</td>
<td>N.A.</td>
<td>7.0</td>
</tr>
<tr>
<td>Ferry</td>
<td>0.6</td>
<td>11.3</td>
<td>1.5</td>
<td>0.05</td>
<td>N.A.</td>
<td>6.4</td>
</tr>
<tr>
<td>Total</td>
<td>0.8</td>
<td>7.2</td>
<td>20.8</td>
<td>0.08</td>
<td>N.A.</td>
<td>6.1</td>
</tr>
</tbody>
</table>

N.A.: Not Applicable (because historical accident frequency is equal to zero).

6. CONCLUDING REMARKS

The “Marine Accident Risk Calculation System” (MARCS) developed by DNV has been used to analyse the probabilities of accidents associated with sea transportation in the Oslofjord. The calculated accident frequencies have been compared with historical data from the DAMA database. Qualitatively, and to a large extent quantitatively, MARCS is able to reproduce historical data. Concerning the quantitative correspondence between the predictions and the observed accident frequencies, the following comments can be made:

- The predicted number of collisions corresponds well to the observed number of collisions.
- For all vessel types except bulk carriers, there is an over-prediction of powered grounding accidents compared to historical data. For ferries, MARCS predicts more than ten times the observed number of accidents. This indicates that the accident parameters used by MARCS, in its present version, does not properly account for the increased alertness when ships travel in the narrow waters of the Oslofjord. Furthermore, most of the vessels have persons who are well known in the Oslofjord on the bridge and this might not be adequately reflected in the MARCS modelling parameters.
- Drift grounding predictions are higher than observed frequencies. For the general cargo type of vessels, MARCS calculates the drift groundings to be more than 26 times the
reported number of drift groundings. The main reason for this large discrepancy is most likely a too high machinery breakdown frequency.

- For fire and explosions and structural failure the MARCS predictions correspond reasonable well to the historical data. However, here it is important to note that since the historical data is scarce one should be careful with drawing to firm conclusions.

Concerning the quantitative comparison between historical data and MARCS calculations, it is important to note that the accidents in the DAMA database are incidents that have been reported to Norwegian authorities, without no distinction between serious and less serious accidents. The accident data for the North Sea and world-wide are, on the other hand, so-called serious accidents recorded in the causality database from Lloyds Maritime Information Services (LMIS). It is expected that the DAMA database contains relative more accidents than the LMIS database. Since internal parameter in MARCS to a large degree have been based on the LMIS accident data, one would expect MARCS to predict less accidents than the corresponding accident frequencies calculated from the DAMA database. However, this seems to be the case for fire and explosions only.

In summary, the results in the present work show that MARCS is well suited to analyse risk associated with sea transport close to the coast and in narrow waters such as the Oslofjord.

REFERENCES


