Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2015, 43 (115), 108–114
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)

Tanker grounding frequency and spills in the Finnish Gulf of Finland

Otto-Ville Edvard Sormunen[1,4], Maria Hänninen[1,4], Jani Häkkinen[2], Antti Posti[3,4]

[1] Department of Applied Mechanics, Aalto University School of Engineering
1A Tietotie, 02150 Espoo, Finland, e-mails: {otto.sormunen; maria.hanninen}@aalto.fi
[2] Finnish Environment Institute (SYKE)
34A Mechelininkatu, Helsinki, Finland, e-mail: jani.hakkinen@ymparisto.fi
[3] University of Turku, FI-20014 TURUN YLIOPISTO, Finland, e-mail: antti.posti@gmail.com
[4] Kotka Maritime Research Association (Merikotka), 7 Heikinkatu, 48100 Kotka, Finland

Key words: groundings, spills, tankers, statistics, maritime safety, transport

Abstract

Groundings and ship collisions are the two most frequent accident types in the Gulf of Finland, which in the past decades has seen an increase in tanker traffic. This has mainly been oil transport from Russia. Both accident types pose a major hazard to the marine ecosystem, as spills of catastrophic magnitude can occur as a consequence. In order to better plan for the response to and/or prevention of accidents, the frequency and size of spills should be known.

This paper estimates the expected number of tanker groundings of different tanker types for the busiest tanker ports in the Finnish part of the Gulf of Finland. Furthermore, in this paper statistics of the sizes of chemical, gas and oil tankers visiting Finnish ports is presented. Finally, the expected number and size of spills is estimated based on the expected number of groundings and the tanker sizes using a spill model based on tanker deadweight (DWT).

Introduction

Groundings are by far the most frequent accident type in the Gulf of Finland (GoF) (Kujala et al., 2009). Oil tanker groundings have resulted in major environmental disasters such as the Exxon Valdez catastrophe. Oil tanker risk analysis and mitigation has received a lot of attention from researchers, companies and governmental agencies but, in the meantime, another risk potential has been largely ignored – the risk posed by chemical tankers (Sormunen, 2012). Chemical tankers carry noxious liquid substances that, when spilled into the sea, can have even more serious environmental consequences than oil (Sormunen et al., 2014). In order to mitigate the risks associated with tanker traffic it is important to understand tanker spill frequencies and sizes. This way one knows the scale of the problem. Knowing this, the next step is to assess what effects certain risk control options would have on lowering the spill frequency, spill size and/or spill consequences.

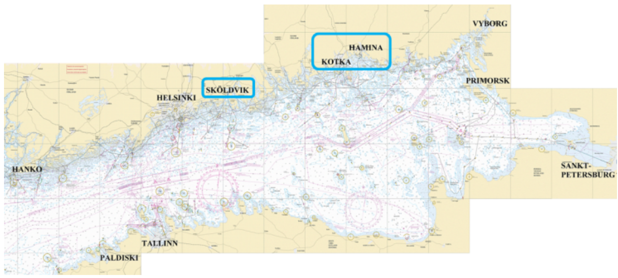

Figure 1. Gulf of Finland with the busiest Finnish tanker harbors highlighted: Porvoo (Sköldvik) and HaminaKotka. Map © Finnish Transport Agency license number 1803/1024/2010

When it comes to modeling tanker grounding risk, there are several challenges. The chain of events leading to grounding is difficult to model as there are so many factors involved see Mazaheri et al. (Mazaheri et al., 2013). Alternatively grounding statistics can be used for, e.g. estimating grounding frequency per 1,000 port calls but then ship and location specific differences are lost. Also there is a problem with underreporting (Hassel, Asbjørnslett

& Hole, 2011). When it comes to modeling grounding damage, the problem is that the damage models are either very general statistical models, very specific finite element models or analytical models that require detailed bottom and damage extent information, see Sormunen (Sormunen, 2014) for an overview.

While the statistical models such as IMO (IMO, 1995), Montewka et al. (Montewka et al., 2010), Papanikolaou et al. (Papanikolaou et al., 2013) and Sormunen (Sormunen, 2014) can be applied for a wide range of situations and ship sizes, their fundamental shortcomings lies in the decoupling of the grounding speed and bottom type with the resulting damage. On the other hand, the finite element-based models, such as Kitamura (Kitamura, 2002) and Alsos and Amdahl (Alsos & Amdahl, 2007) allow a detailed analysis but currently deal with limited case scenarios that not only require very detailed input (Sormunen, 2014) and are also computationally intensive (Heinvee, Tabri & Kõrgesaar, 2013), thus restricting practical application on a large-scale basis, such as when trying to model all tanker groundings in a given area over a longer time period.

The analytical models such as Zhu et al. (Zhu, James & Zhang, 2002), Cerup-Simonsen et al. (2009) and Heinvee et al. (Heinvee, Tabri & Kõrgesaar, 2013), on the other hand, are relatively simple and fast to calculate with, but require the exact shape of the bottom as well as the damage extent in one dimension to be known. This data that is not readily available, see Sormunen (Sormunen, 2014) for a more in-depth discussion. If the exact size of the opening and the tanker layout is known, the spill size and outflow velocity can be modeled with Computational Fluid Dynamics, see, for example, Krata et al. (Krata, Jachowski & Montweka, 2012) and Tavakoli et al. (Tavakoli, Amdahl & Leira, 2012).

Another issue with missing or unreliable data is when trying to determine tanker type by their AIS (Automatic Identification System) self-identification tag, the data might be vague or inaccurate, as pointed out in Sormunen (Sormunen, 2011).

For the purposes of this paper, the grounding spill model proposed by Montewka et al. (Montewka et al., 2010) is selected due to the general nature of the spill model as that it can be applied to all tanker visits in the GoF. This model does, however, have its limitations in not being able to link the grounding speed or other factors with the resulting damage. The model proposed by van de Wiel and van Dorp (Wiel & Drop, 2009) does this link but only models the outflow for two different tanker sizes of 40,000 and 150,000 deadweight (DWT), which is not enough for the purposes of this paper. This paper is structured as follows: first, statistics of the number tanker visits, tanker sizes, types and number of accidents is presented. Based on this, the number of groundings is estimated along with the spill sizes. Lastly, the reliability of the results are analyzed using an uncertainty assessment analysis framework.

Tanker calls and grounding statistics

For estimating the number of tanker groundings and their frequency relative to the traffic volume, the first step is to have a look at the port call statistics in more detail. One of the most comprehensive and most accurate estimates comes from the Finnish Transportation Agency (FTA, 2012). In its statistics, the number of tankers calling into Finnish harbors has remained quite steady at slightly more than 2,000 tanker arrivals per year during 2002–2011 with the count after the financial crisis reaching a low point in 2009, when the number of arriving tankers was only 1,811 (FTA, 2012). The specific tanker port calls in 2011 are as follows (Table 1).

Based on traffic statistics from the FTA and accident statistics obtained from HELCOM (Baltic Marine Environment Protection Commission) and the DAMA (Data Management Association) database, the number of groundings in Finnish territorial waters per 1,000 arrivals is calculated (Table 2).

Table 1. Arriving tankers according to FTA in Finnish Gulf of Finland harbors (FTA, 2012)

Harbor	Tanker arrivals in 2011	Share of total in %
HaminaKotka	460	33.41
Loviisa	2	0.15
Porvoo (Sköldvik)	884	64.20
Helsinki	8	0.58
Kantvik	5	0.36
Inkoo	2	0.15
Förby	16	1.16
Total:	**1,377**	**100**

Table 2. Groundings compared to port arrivals in Finland

Year	Groundings per 1000 port arrivals	Grounding causation factor PG
1997	0.533	0.000533
1998	0.710	0.000710
1999	0.297	0.000297
2001	0.400	0.000400
2002	0.214	0.000214
2003	0.262	0.000262
2004	0.141	0.000141
2005	0.097	0.000097
Average:	**0.332**	**0.000332**

If the groundings per 1,000 port visits are divided by 1,000, the grounding causation factor or P_G is obtained, which tells the probability that a single ship visit to a port will lead to grounding. As the number of tanker groundings in Finnish territorial waters is low (8 reported with known location since 1990), the general grounding frequency is used in this case.

Based on the number of arrivals and the average grounding frequency, the expected number of groundings per harbor h is calculated:

$$E(\text{groundings})_{h,t} = N_{h,t} \cdot \text{mean}(GPA) \quad (1)$$

where t = year, GPA = groundings per 1,000 port arrivals and N the number of tanker arrivals visits. The results are as follows (Table 3).

Table 3. Expected yearly groundings based on 2011 traffic volume and average grounding probability per 1000 arrivals

Harbor	Expected groundings / year
HaminaKotka	0.153
Loviisa	0.00066
Porvoo (Sköldvik)	0.293
Helsinki	0.00265
Kantvik	0.00166
Inkoo	0.00066
Förby	0.00531
Total:	**0.457**

These figures can be put into perspective by comparing them to the GoF collision frequency estimates: The results of Sormunen (Sormunen, 2012) show that, based on traffic simulation, the expected number of yearly collisions where a tanker is hit by another ship is 0.235–0.0597 depending on the causation factor used (Goerlandt & Kujala, 2011; Hänninen & Kujala, 2012). The statistics reported by Kujala et al. (Kujala et al., 2009) show that the ship-ship collision to grounding accident ratio is 1:2.38. The corresponding numbers here are 1:1.94 and 1:7.65, respectively. However, a straight comparison is not possible as the grounding numbers presented here are for all ship types. Also the traffic simulation in Sormunen (Sormunen, 2012) and Sormunen et al. (Sormunen et al., 2014) could not take into account ice conditions.

As the two busiest lanes account for 97.61% of all Finnish GoF tanker traffic, grounding calculations are here done for these two harbors only. Based on a more detailed analysis on tanker traffic data from PortNet, the following data regarding tanker DWT distributions is obtained (Figure 2).

In Figure 2, the y-axis is the number of port visits. The x-axis is the tanker DWT in 10,000 tons, thus the bars in the figure represent 0–10,000, 10,000–20,000, and 150,000–160,000 DWT. The chemical and gas tanker histogram bin sizes are 2,500 DWT, so the bars represent 0–2,500, 2,500–5,000, and 17,500–20,000 DWT. As can be seen, all gas and chemical tankers are below 20,000 DWT as well as most oil tankers, however, oil tankers larger than 100,000 DWT have also visited Porvoo. The oil tankers form a numerical huge majority compared to the other types of tankers.

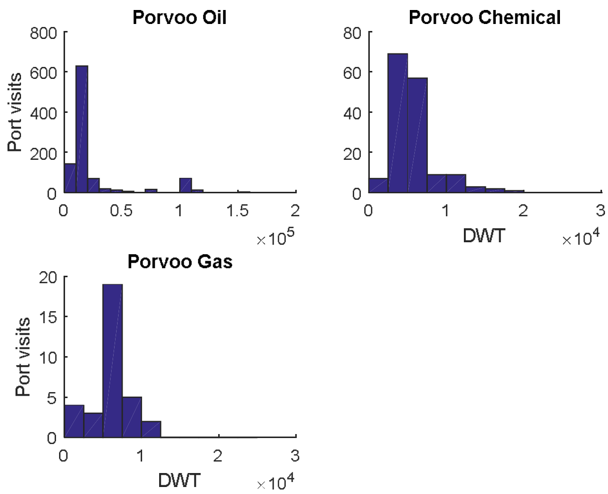

Figure 2. DWT statistics of tankers visiting Porvoo

When it comes to HaminaKotka harbor, also all of the tankers (except one) of were below 20,000 DWT, as illustrated in Figure 3.

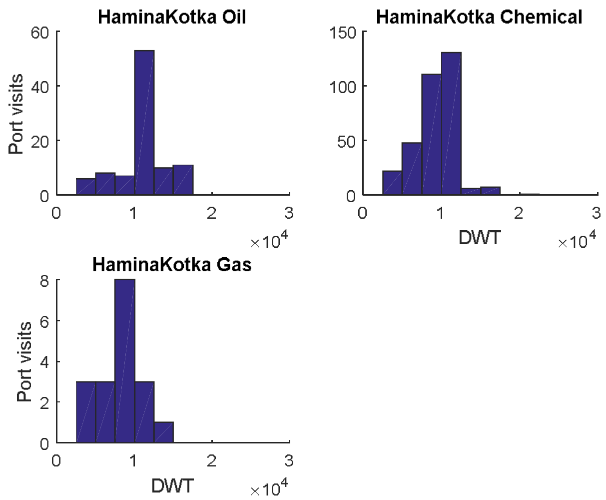

Figure 3. DWT statistics of tankers visiting HaminaKotka

In the HaminaKotka Figure histograms, all the bin sizes are 2,500 DWT. The statistics of the figures for tankers up to 20,000 DWT are presented in Table 4, where the percentage division into gas, oil and chemical tankers based on DWT is shown. The rows indicate the category according to harbor and DWT range. The average values are for Porvoo and HaminaKotka combined.

Table 4. Share of port calls of different tanker types divided into DWT range and harbor

Harbor	DWT range	Of which chemical tankers	Gas tankers	Oil tankers
Porvoo	< 10 K	45.08%	9.84%	45.08%
	10–20 K	2.32%	0.31%	97.37%
HaminaKotka	< 10 K	83.80%	6.48%	9.72%
	10–20 K	64.86%	1.80%	33.33%
Average	**< 10 K**	**60.83%**	**8.47%**	**30.70%**
	10–20 K	**18.32%**	**0.69%**	**80.99%**

Table 4 shows that for Porvoo, the < 10,000 DWT tankers are almost 50–50 chemical and oil tankers. If we go above 10,000 DWT, the tankers are almost exclusively oil tankers.

For HaminaKotka there is a similar pattern, where chemical tankers constitute 2/3 of the 10–20,000 DWT tanker visits. In the < 10,000 DWT range, 80% of tankers are chemical tankers. The share of gas tankers is below 10% in all cases.

The classification of tankers into oil, gas or chemical is based on individual port visit reports on which of these three cargo types the tanker was carrying. This gives a more reliable picture of the actual type of tanker than just looking at the AIS data tag or the ship classification, as many tankers either just declare themselves as "tanker, general" or have double classifications as oil and chemical tankers. This approach was taken in Sormunen (Sormunen, 2011; 2012), where it was suspected that many of the 40,000 DWT tankers were chemical tankers and that there might even be individual visits to Finnish harbors by tankers in the range 80–100,000 DWT carrying chemicals.

Based on the findings here, it is more realistic to assume that the de facto chemical tankers are if not exclusively then mainly below 20,000 DWT. There is still some uncertainty with regard to the statistics: for most tankers the statistics do contain both the arrival and departure statistics, but for some only one or the other. Also the PortNet statistics had overlapping departure notifications when the same tanker would have multiple destinations. After filtering out multiple entries, the total number of tankers visiting Porvoo in 2011 was 1,178 and for HaminaKotka 439, whereas the FTA statistics show 884 and 460 visits to these harbors respectively. This equals an expected number a total of 0.391 tanker groundings per year for Porvoo and 0.146 for Hamina Kotka using the PortNet data, and 0.293 and 0.153 groundings per year respectively using the FTA statistics.

Now that we know the number and size of tankers as well as the grounding frequency, the next step is to calculate the spill probability in case of grounding as well as the resulting spill sizes which are done in the following chapters.

Spill size estimation

The spill model used in this paper is by Montewka et al. (Montewka et al., 2010) and uses a modified IMO methodology. It presents a logistic distribution for estimating oil tanker spill sizes in case of collision or grounding which has the following probability density function:

$$f(x;\mu,s)=\frac{e^{-(x-\mu)/s}}{s\left(1+e^{-(x-\mu)/s}\right)^2} \tag{2}$$

where s (> 0) is the scale parameter and μ the location parameter. Montewka et al. (Montewka et al., 2010) carried out simulations for discrete tanker sizes to obtain the function parameters and fitted a distribution to the expected mean spill volume as a function of tanker DWT, as presented in Figure 4.

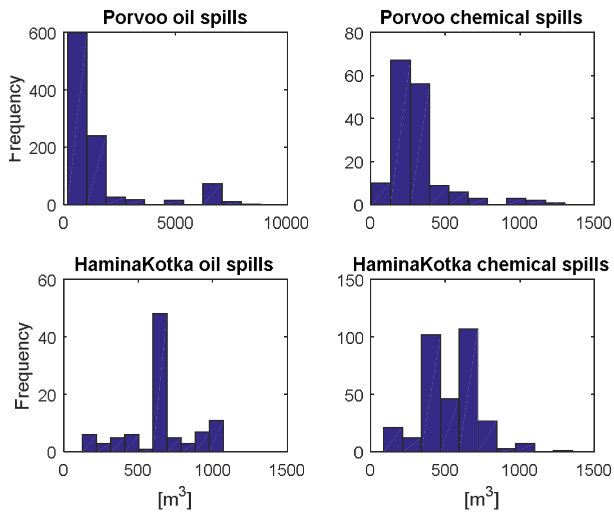

Figure 4. Histogram of expected spill sizes using spill model by Montewka et al. (Montewka et al., 2010)

Using this model and the PortNet tanker statistics, the following expected spill sizes are obtained for different tankers in the different areas.

The histogram is based on calculating the expected spill size for each tanker that visited Porvoo and HaminaKotka. As mentioned earlier, only a fraction of tankers visiting harbors end up being grounded. The probability that a tanker grounding leads to a spill is estimated by the Marine Board and Transport Research Board (TRB, 2001) to be 6% for tankers of 40,000 DWT and 27% for tankers of 150,000 DWT. Based on this, the authors did a linear interpolation assuming that the spill probability in case of grounding is a linear function of tanker DWT in order to assess probability of spills in case of grounding:

$$\Pr(\text{spill}|\text{DWT}) = \\ = \begin{cases} 0.06 & \text{if DWT} \leq 40\,\text{Kt} \\ -0.0164 + 1.9091 \cdot 10^{-6}\,\text{DWT} & \\ & \text{if } 40\,\text{Kt} < \text{DWT} < 150\,\text{Kt} \\ 0.27 & \text{if DWT} \geq 150\,\text{Kt} \end{cases} \tag{3}$$

The total expected spill size of substance i = {gas, oil, chemicals} per harbor h = {Porvoo, HaminaKotka} for visiting tankers t = 1,2,3, T can be expressed as follows:

$$V_{\text{total }h,i} = 1.11 P_G \sum_{t=1}^{T} Pr(\text{spill}|\text{DWT}_{t,i,h}) * \\ \left(-9 \cdot 10^{-8}\,\text{DWT}_{t,i,h}^2 + 0.0662\,\text{DWT}_{t,i,h} - 113.86\right) \tag{4}$$

where 1.11 is a multiplier taken from Sormunen (Sormunen, 2011) describing the relationship between chemical tanker DWT and total cargo tank volume, P_G is the grounding causation factor and $V_{\text{total }h,i}$ is the total spill volume in m^3 per year, making a conservative assumption that all tankers always sail fully laden. This assumption of course does not fully correspond with reality but is useful in risk estimation, where the important scenarios are not the best-case but the worst-case scenarios.

Table 5 summarizes all the previous calculations.

The return period indicates how many years on average are between two different accidents, calculated as 1/E (accidents per year). The overall row is for Porvoo and HaminaKotka combined. The expected number of spills (column 5) is calculated as the expected number of groundings multiplied by the average probability of spill given a grounding. The last column summarizes Figure 4, giving the expected spill size in case of a spill. For oil tankers, the expected spill sizes are much higher than for other tanker types, especially in Porvoo.

Result uncertainty

Having estimated the grounding frequency and spill sizes, the remaining question is how reliable are the results? In order to assess this, the uncertainty assessment analysis (UAA) framework presented in Sormunen et al. (Sormunen et al., 2014) is used. In this the degree of uncertainty is classified following the criterion set by Milazzo and Aven (Milazzo & Aven, 2012):

<u>Low (L)</u> if one or more of the following conditions are met:

- The assumptions made are seen as very reasonable;
- Much reliable data is available;
- There is broad agreement/consensus among experts;
- The phenomena involved are well understood; the models used are known to give predictions with the required accuracy.

<u>High (H)</u> if one or more of the following conditions are met:

- The assumptions made represent strong simplifications;
- Data is not available or unreliable;
- There is a lack of agreement/consensus among experts;
- The phenomena involved are not well understood; models are non-existent or known/ believed to give poor predictions.

<u>Medium (M)</u> if conditions between those characterizing low and high uncertainty exist.

The uncertainty score is assessed separately for epistemic uncertainty (i.e., how well is the phenomena understood and recorded), sensitivity (i.e., how much changes in one variable values affect the outcome) and the uncertainty of the sensitivity (i.e., how well we can model the sensitivity).

The final score "importance" is assessed as an "average" of the epistemic uncertainty and the arg max (sensitivity, sensitivity uncertainty).

In Table 6 all the different model parts have medium or high uncertainty. This means that there is significant uncertainty regarding the results, which must be taken into account when using the results, such as for decision making. The un-

Table 5. Summary of Grounding and spill calculations

		E(groundings) per year	Return period	E(spills) per year	Return period	$V_{\text{total }h,i}$	E(spill size) in m^3
Porvoo tankers	Oil	0.327	3.1	0.023936	41.8	58.17	1529.1
	Gas	0.011	90.9	0.00066	1515.2	0.20	301.6
	Chemical	0.0521	19.2	0.00313	319.9	0.92	294.6
	Total	**0.390**	**2.6**	**0.0277**	**36.1**	**59.29**	**1328.1**
Hamina Kotka tankers	Oil	0.0315	31.7	0.00189	529.1	1.28	673.9
	Gas	0.006	166.7	0.00036	2777.8	0.17	465.1
	Chemical	0.108	9.3	0.00648	154.3	3.56	548.3
	Total	**0.1455**	**6.9**	**0.00873**	**114.5**	**5.00**	**515.4**
	Overall	**0.5356**	**1.9**	**0.0365**	**27.4**	**64.29**	**1011.6**

Table 6. Uncertainty assessment analysis

Model part	Epistemic uncertainty	Main reasons	Sensi-tivity	Main reasons	Sensitivity uncertainty	Main reasons	Impor-tance
Number of port calls	L	Complete database	H	A direct multi-plier of risk, see eq. (4)	L	Sensitivity is modeled in eq. (4)	M
Tanker type classification	M	Not all port call reports contain both the in- and as well as the outbound- reports	H	same as previous	L	same as previous	M
Tanker size	Unknown	Not known if DWT is based on self-reports, which are not always reliable, see Sormunen (2012)	H	same as previous	L	same as previous	M
Grounding frequency	H	Underreporting, grounding frequency per year and location varies a lot	H	same as previous	L	same as previous	H
Spill size estimation	H	Major simplifications in spill probability and the outflow model	H	same as previous	L	same as previous	H

certainty coupled with the stochastic nature of the accidents means that it cannot be exactly predicted when and where an accident will happen. When it comes to the spill size estimation, especially the spill outflow, the model is simplified as it does not properly take into account differences in the tanker subdivisions between the different tanker types. Modeling this in detail is a suggestion for future research. Note that lane-specific factors other than traffic volume and tanker DWT and type are not modeled here but are left for future research. These factors include things such as differences in bottom shapes and location-sensitive grounding probability.

Conclusions

The expected number of yearly groundings is 0.39 for Porvoo, which is more than double that of HaminaKotka (0.15). This equals one grounding on average every 2.6/6.9 years for Porvoo and HaminaKotka, respectively. However, since the probability of spill in case of grounding is small, it is expected that a tanker spill will happen on average only once every 36/115 years. For chemical tankers specifically, the return period is quite long: A spill is expected on average once every 320/154 years in Porvoo and HaminaKotka. For gas tankers a leak is expected not even once per millennia. Thus chemical tanker (and especially gas tanker) spills in the GoF due to chemical tanker grounding are expected to be a very rare event. In case of a spill, the expected spill sizes are 295 m^3 for Porvoo and 548 m^3 for HaminaKotka, which is relatively little compared to the average expected oil spill size: 1,529 m^3 and 674 m^3.

Despite the fact that according to statistics groundings are 2.38 times more frequent in the GoF than collisions, groundings also seem to lead to spills much less frequently: For GoF chemical tankers the spill probability in case of grounding is 6% – for collisions it is 2.33 times higher: 14% according to TRB (TRB, 2001). The results of Goerlandt et al. (Goerlandt, Ståhlberg & Kujala, 2012) indicate that the probability of breach in case of a tanker being struck by another ship is much higher: in the range 40–80% in the GoF depending on the assumptions. According to Montewka et al. (Montewka et al., 2010), the expected spill sizes as a function of tanker DWT are also much higher in collisions. Note however, as groundings happen closer to shore, their environmental impact is higher per ton of spilled noxious liquid substance. Another simplification is that the Montewka et al. (Montewka et al., 2010) model is for oil tankers, the justification for using it for chemical tankers as well here is based on most of the tankers being dual-classified and as such relatively close to one another in structure, see Sormunen (Sormunen, 2011). Furthermore, the estimates here did not include accident underreporting, which is significant even for Nordic countries (Hassel, Asbjørnslett & Hole, 2011). With regards to the uncertainty, the results in this paper are associated with medium to high uncertainty in a similar fashion when modeling the tanker collision damage in Sormunen et al. (Sormunen et al., 2014), which must be taken into account when using the results. If this uncertainty is not taken into consideration in decision making or analysis that builds on these results, one will get a false sense of reliability.

Suggestions for future research

In order to make a more accurate and reliable grounding damage risk analysis, the following suggestions for future research are made:

- Investigating harbor-specific grounding causation factors;
- Developing a general tanker spill model that links local conditions such as velocities and

bottom shape with the resulting damage for all possible tanker sizes;
- Developing a tanker spill model for chemical and gas tankers specifically.

Acknowledgments

This paper was carried out as a part of the TEKES and EU-funded CHEMBALTIC project in cooperation with Merikotka, NesteOil, Vopak, Port of HaminaKotka, FTA, Finnish Port Association and Finnish Shipowners' Association. The authors wish to express their gratitude to the funders.

References

1. ALSOS, H. & AMDAHL, J. (2007) On the resistance of tanker bottom structures during stranding. *Marine Structures*. 20. pp. 218–237.
2. CERUP-SIMONSEN, B., TÖRNQVIST, R. & LÜTZEN, M. (2009) A simplified grounding damage prediction method and its application in modern damage stability requirements. *Marine Structures*. 22(1). pp. 62–83.
3. FTA (2012) Finnish Transportation Agency. Ulkomaan meriliikennetilasto 2011.
4. GOERLANDT, F., STÅHLBERG, K. & KUJALA, P. (2012) Influence of impact scenario models on collision risk analysis. *Ocean engineering*. 47. pp. 74–87.
5. GOERLANDT, F. & KUJALA, P. (2011) Traffic Based Ship Collision Probability and Modeling. *Reliability Engineering and System Safety*. 96 (1). pp. 91–107.
6. HÄNNINEN, M. & KUJALA, P. (2012) Influences of Variables on Ship Collision Probability in a Bayesian Belief Network Model. *Reliability Engineering & System Safety*. 102. pp. 27–40.
7. HASSEL, M., ASBJØRNSLETT, B. & HOLE, L. (2011) Underreporting of maritime accidents to vessel accident databases. *Accident Analysis & Prevention*. 43 (6). pp. 2053–2063.
8. HEINVEE, M., TABRI, K. & KÕRGESAAR, M. (2013) A simplified approach to predict the bottom damage in tanker grounding. in: *Proceedings of the 6th International Conference on Collision and Grounding of Ship and Offshore Structures*. Trondheim 17–19. June 2013. Available online from: http://www.ntnu.no/iccgs [Accessed: 23 January 2014]
9. IMO (1995) International Maritime Organization. *Interim guidelines for approval of alternative methods of design and construction of oil tankers under regulation 13F(5) of Annex I of MARPOL 73/78*. Technical Report, Resolution MEPC, 66(37), 1995.
10. KITAMURA, O. (2002) FEM approach to the simulation of collision and grounding damage. *Marine Structures*. 15. pp. 403–428.
11. KRATA, P., JACHOWSKI, J. & MONTWEKA, J. (2012) Modeling of Accidental Bunker Oil Spills as a Result of Ship's Bunker Tanks Rupture – a Case Study. *International Journal on Marine Navigation and Safety of Sea Transportation*. 6 (4). pp.495–500.
12. KUJALA, P., HÄNNINEN, M., AROLA, T. & YLITALO, J. (2009) Analysis of the Marine Traffic Safety in the Gulf of Finland. *Reliability Engineering and System Safety*. 9. pp. 1349–1357.
13. TRB (2001) Marine Board and Transport Research Board. Environmental Performance of Tanker Designs in Collision and Grounding: Method for Comparision – Special Report 259. Washington D.C.: National Academy Press.
14. MAZAHERI, A., SORMUNEN, O-V., HYTTINEN, N., MONTEWKA, J. & KUJALA, P. (2013) Comparison of the learning algorithms for evidence-based BBN modeling – A case study on ship grounding accidents. in: *Proceedings of the ESREL 2013 Conference*. 29 September – 2 October 2013, Asterdam, the Netherlands.
15. MILAZZO, M. & AVEN, T. (2012) An extended risk assessment approach for chemical plants applied to a study related to pipe ruptures. *Reliability Engineering and System Safety*. 99. pp. 183–192.
16. MONTEWKA, J., STÅHLBERG, K., SEPPÄLÄ, T. & KUJALA, P. (2010) Elements of risk analysis for collision of oil tankers. in: *Risk, Reliability and Safety*. pp. 1005–1013, London: Taylor and Francis Group.
17. PAPANIKOLAOU, A., HAMANN, R., LEE, B., MAINS, C., OLUFSEN, O., VASSALOS, D. & ZARAPHONITIS, G. (2013) GOALDS–Goal Based Damage Ship Stability and safety standards. *Accident Analysis and Prevention*. 60 November. pp. 353–365.
18. SORMUNEN, O-V. (2011) *Mitigating Environmental Risks of Chemical Tanker Collisions with Recovery Vessels in the Gulf of Finland*. Master's Thesis. Hanken Swedish School of Economics.
19. SORMUNEN, O-V. (2012) *Spill estimation of chemical tanker collisions in the Gulf of Finland*. Master's Thesis. Finland: Aalto University.
20. SORMUNEN, O-V. (2014) Ship Grounding Damage Estimation Using Statistical Models. in: *Proceedings of the PSAM'12 Conference*. 22–27 June 2014, Honololu, USA.
21. SORMUNEN, O-V., GOERLANDT, F., HÄKKINEN, J., POSTI, A., HÄNNINEN, M., MONTEWKA, J., STÅHLBERG, K. & KUJALA, P. (2014) Uncertainty in maritime risk analysis: Extended case study on chemical tanker collisions. in: *Proceedings of the Institution of Mechanical Engineers. Part M: Journal of Engineering for the Maritime Environment*. doi: 10.1177/1475090213515640.
22. TAVAKOLI, M., AMDAHL, J. & LEIRA, B. (2012) Analytical and numerical modelling of oil spill from a side tank with collision damage. *Ships and Offshore Structures*. 7 (1). pp. 73–86.
23. WIEL, G. van de & DORP, J. van (2009) An oil outflow model for tanker collisions and groundings. *Annals of Operations Research*. 26 (1). pp. 1–26.
24. ZHU, L., JAMES, P. & ZHANG, S. (2002) Statistics and damage assessment of ship grounding, *Marine Structures*. 15 (4–5). pp. 515–530.