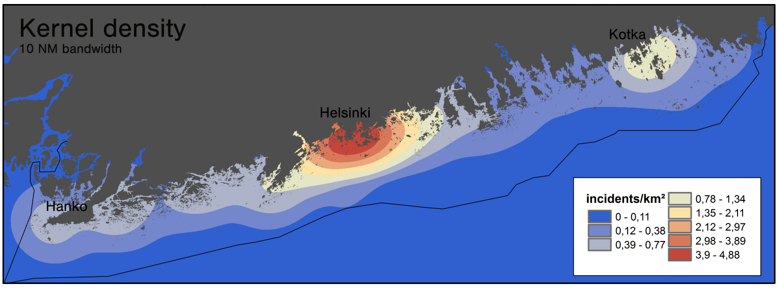
Department of Applied Mechanics

Risk Assessment and Management for Maritime SAR and Oil Spill Response

Edited by:
Floris Goerlandt, Vadim Goncharov and Otto-Ville Sormunen

Contributors:
Floris Goerlandt, Vadim Goncharov, Jenny Jemli, Natalia Klementieva, Pentti Kujala, Jakub Montewka, Maikki Sonninen, Otto-Ville Sormunen, Kaarle Ståhlberg, Fatemeh Torabihaghighi and Emilia Venäläinen



Aalto University

SCIENCE +
TECHNOLOGY

RESEARCH REPORT

Aalto University publication series
SCIENCE + TECHNOLOGY 6/2014

Risk Assessment and Management for Maritime SAR and Oil Spill Response

Edited by:
Floris Goerlandt, Vadim Goncharov and Otto-Ville Sormunen

Contributors:
Floris Goerlandt, Vadim Goncharov, Jenny Jemli, Natalia Klementieva, Pentti Kujala, Jakub Montewka, Maikki Sonninen, Otto-Ville Sormunen, Kaarle Ståhlberg, Fatemeh Torabihaghighi and Emilia Venäläinen

Aalto University
School of Engineering
Department of Applied Mechanics
Research Group on Maritime Risk and Safety

Aalto University publication series
SCIENCE + **TECHNOLOGY** 6/2014

Floris Goerlandt, Vadim Goncharov and Otto-Ville Sormunen

Contributors:
Floris Goerlandt, Vadim Goncharov, Jenny Jemli, Natalia Klementieva, Pentti Kujala, Jakub Montewka, Maikki Sonninen, Otto-Ville Sormunen, Kaarle Ståhlberg, Fatemeh Torabihaghighi and Emilia Venäläinen

ISBN 978-952-60-5725-5 (pdf)
ISSN-L 1799-4896
ISSN 1799-4896 (printed)
ISSN 1799-490X (pdf)
http://urn.fi/URN:ISBN:978-952-60-5725-5

Unigrafia Oy
Helsinki 2014

Finland

This publication was founded by the RescOp project.

Aalto University

Aalto University, P.O. Box 11000, FI-00076 Aalto www.aalto.fi

Abstract

Author

Name of the publication Risk Assessment and Management for Maritime SAR and Oil Spill Response	
Publisher School of Engineering	
Unit Department of Applied Mechanics	
Series Aalto University publication series SCIENCE + TECHNOLOGY 6/2014	
Field of research Maritime Risk Analysis	

Abstract

This report summarizes selected publications that deal with maritime Search and Rescue (SAR) operations, winter navigation as well as oil spill response.

In the first part of this report, the SAR capabilities, response times and effects of weather on Finnish Search and Rescue Units (SRUs) are evaluated. Besides this, the risk of oil spill and effects of winter conditions were evaluated. Two of the most relevant accident types – collisions consequences on oil tanker and RoPAx vessels – were evaluated. Both tankers as well as RoPax vessels are very common vessels in the Gulf of Finland, carrying thousands passengers or tonnes of oil. However, during the project it was found that there are currently no particularly reliable methods for assessing which sea areas are most prone to accidents. This highlights the need for future research in the methodology.

Furthermore, a model is presented that describes the interaction between ships and the ice when navigating in an ice channel. This model helps to understand better the increased side forces and yaw that occurs in ice channel when compared to sailing in open waters. This can be used to train bridge personnel to better understand their ship's behavior under challenging ice channel conditions, thus decreasing risk. A final model describes how fast an oil slick will spread in an ice channel as a function of factors such as the ice concentration and ice floe size, allowing for better estimation of how far oil will spread until effective clean-up measures can be taken.

Keywords Search and Rescue, Maritime transportation, Risk assessment, Oil spill modeling, Ice channel navigation

ISBN (printed)	**ISBN (pdf)** 978-952-60-5725-5	
ISSN-L 1799-4896	**ISSN (printed)** 1799-4896	**ISSN (pdf)** 1799-490X
Location of publisher Helsinki	**Location of printing** Helsinki	**Year** 2014
Pages	**urn** http://urn.fi/URN:ISBN:978-952-60-5725-5	

Contents

1. Introduction

This report is to provide an overview of various elements for the risk assessment and management for Search and Rescue (SAR) and emergency spill response. The project focuses on assessing risk related to recreational boating and the strategic response capacity of the volunteer rescue organizations in Finland and Russia, specifically in the Gulf of Finland. Furthermore, various advances are made for response-oriented risk assessment of maritime transportation, both in open water and ice conditions. This is done for SAR as well as oil spill response.

The present report only aims to provide a general overview, briefly summarizing various reports and papers. For more details, see the stand-alone publications. These references are gathered in the Appendix to the report and are available via the following website: www.merikotka.fi/rescop

The report first presents the various analyses and developed methods for SAR risk management aimed at recreational boating and volunteer rescue organizations. Then, various studies related to risk assessment of maritime transportation are shown, first in open water and finally in ice.

2. Risk assessment and management for SAR response for recreational boating

The work done related to recreational boating and SAR response broadly falls under risk assessment studies and tools for risk management. The studies supporting risk assessment provide a set of data and system analysis, which provide insight in the current status of the boating incidents and SAR capability. The developed tools for risk management enable an analysis of the SAR response, by means of which strategic decision alternatives can be evaluated.

In terms of risk assessment, following themes are addressed:

- Visualization and statistical analysis of SAR missions in the Finnish waters
- Visual data mining of boating incidents, SAR response and environmental conditions
- Capability assessment of the Finnish SAR in the Gulf of Finland

In terms of risk management, following themes are addressed:

- Development of a maritime SAR response simulation tool for Finnish Gulf of Finland
- Application of the maritime SAR response simulation tool for Russian Gulf of Finland
- Development of a SAR capability assessment tool

Each of these themes is briefly introduced in the following sections.

2.1. Visualization and analysis of SAR missions in Finnish waters

A first report visualizes all the SAR missions which are recorded in the Finnish waters over the period 2007-2012.

The SAR mission data has been regarded the most informative data source to obtain insight in the activities of the recreational boaters in the Finnish waters and the demand level for SAR resources in various areas. While there is information regarding the number of registered boats in the various municipalities in Finland (Räsänen et al., 2005), this provides only a very general picture of the potential boating activities in the sea and lake areas. No more detailed information is at present available for Finland, apart from general usage reports of visitors to marine recreation areas (Neuvonen et al., 2009). In Russian waters, it has not been possible to obtain specific data concerning the number of boating incidents or registered vessels. A description of the boating situation is provided by Deltamarin (2006).

One possible method for obtaining more detailed information regarding boating patterns in sea areas has been considered, namely the use of on-the-water surveys as in Gray et al. (2011). This, however, was considered too time-consuming, having the additional limitation that only relatively small areas can be covered in such questionnaires. Advanced remote sensing tools exist (Pegler, 2004), but these are beyond the scope of the current project.

The SAR mission data has been made available by the Finnish Boarder Guard, the Finnish Rescue Services and the Finnish Lifeboat Institution. While each of these organizations operates an independent database, the information has not before been put together to obtain an integrated and comprehensive picture of the SAR demands in various areas across Finland.

Thus, a comprehensive atlas of the SAR missions in Finland has been developed, visualizing the SAR operations on a national, regional and local level (Venäläinen and Sonninen, 2013). The atlas furthermore contains several statistical data analyses, focusing on the demand level of each station of the Finnish Lifeboat Institution. These include the number of missions over the course of the year, the types of assisted vessels, the types of performed missions, the distances from the base station to the incident locations and several others. For this task, it was decided that the SAR demand would be investigated for the entire Finnish territory, both at sea and in lake areas. This thus stretches beyond the Gulf of Finland, but it was deemed relatively little extra work, while the total picture would be more informative for the Finnish Lifeboat Institution than a sole focus on the Finnish waters of the Gulf of Finland.

The evidence generated in the atlas is useful for risk-informed decision making concerning the organization of the SAR response fleet, providing an unprecedented insight in the actual activity level and SAR demand in various areas across Finland.

A number of example maps and analysis on the following pages the content of this report, for the local situation in the Kotka area.

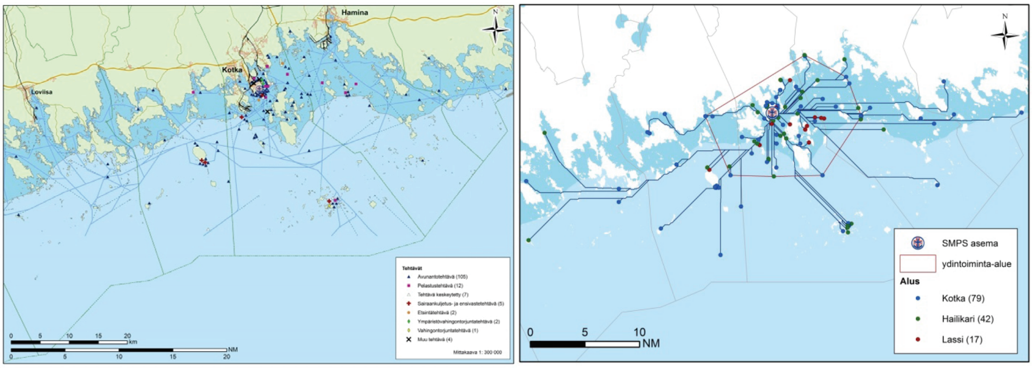
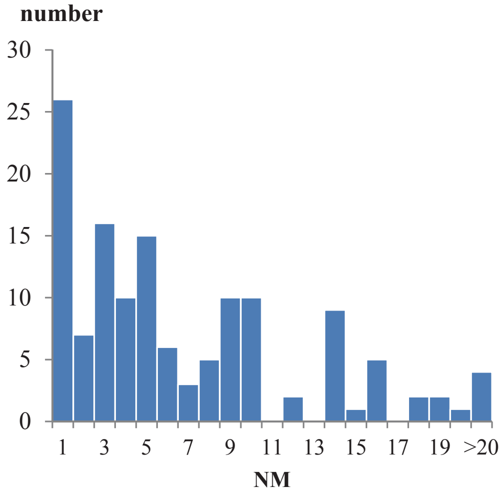


Figure 1 **Visualization of SAR missions by incident type, Kotka-Hamina area (left) and distance-based core activity area (right), Kotka FLI station (Venäläinen and Sonninen, 2013)**



140 missions	NM
Mean	6,47
Median	4,54
Maximumi	28,10
Total	867,13

	Mission time breakdown		
140 missions	Travel [hours]	On site [hours]	Total [hours]
Mean	0.35	1.50	1.85
Median	0.285	1.18	1.49
Maximum	1.335	6.58	7.33
Total	48.5	210.2	258.7

Figure 2 **Analysis of travel distances and operation time in SAR missions, Kotka station (Venäläinen and Sonninen, 2013)**

These analyses are performed for all stations of the Finnish Lifeboat Institution, and aggregated results are shown for larger areas. In addition, several analyses related to the incident type and the type of recreational vessels are performed as well.

2.2. Capability assessment of the Finnish SAR in the Gulf of Finland

A second report concerning risk assessment for the SAR response in the Gulf of Finland uses state-of-the-art spatial analysis software for the processing and integration of various types of information regarding the SAR response performance in the area. The analysis utilizes set of SAR system indicators that reflect the need for certain rescue capacity in various locations around the Gulf of Finland. As the method relies heavily on data, which only has been available for Finnish waters, only the Finnish areas of the Gulf of Finland are considered.

The set of indicators derived from the analyses is qualitatively considered in a holistic sense, enabling an evidence-based risk evaluation of the considered sea area. The integration and combination of a variety of earlier unconnected sets of data, augmented with spatial analyses, clearly shows the methodological applicability of geo-spatial tools for risk-informed SRU planning.

The spatial risk is considered using a set of indicators, which provide various elements of information regarding the accident occurrence and response capacity in spatial and temporal sense. Following indicators are considered: density of incidents, time of incidents, probability of simultaneous occurrence of incidents, environmental conditions under which incidents occur and SAR related aspects such as the potential of search and rescue units (SRUs) to cover sea areas within a specified time, either by itself or with multiple SRUs.

For the Finnish Finnish part of Gulf of Finland SAR is operated by the Finnish Border Guard (Rajavartiolaitos, RAJA) and by the Finnish Lifeboat Institution (Suomen meripelastusseura, SMPS) (Jemli, 2012). RAJA is the leading SAR authority in Finland whereas SMPS is volunteer-based, having 150 SAR vessels and 2000 volunteers. An abridged overview of some performed analyses is shown in Figure 3. See Goerlandt, Torabihaghighi and Kujala (2013) and Goerlandt et al. (2012) for more details.

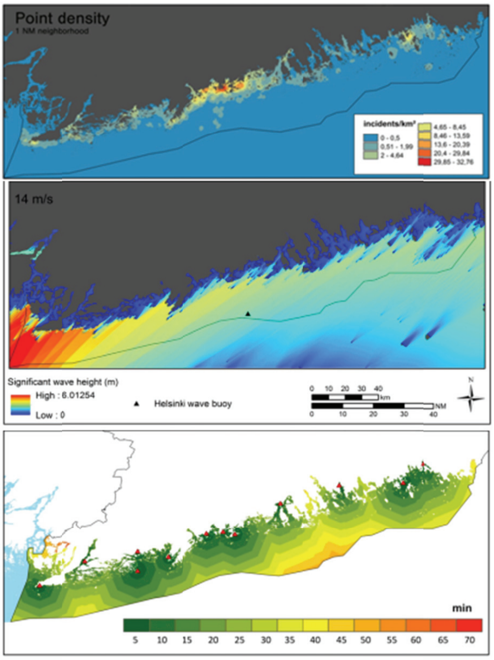


Figure 3 Accident occurance density, wave height at 14 m/s wind and SRU response time

In good weather conditions most the Finnish GoF can be reached by a SRU within 20 minutes of setting sail. In the simulation, most incidents are responded to in less than 15 minutes but travel times up to 50 minutes also do occur (Goerlandt, Torabihaghighi and Kujala, 2013), see Figure 4

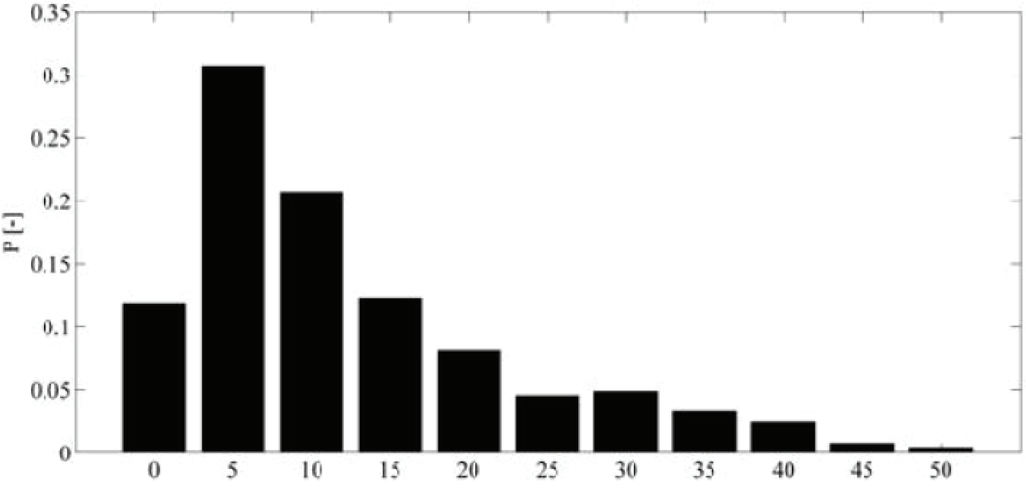


Figure 4 Travel time distribution for SAR missions (Goerlandt, Torabihaghighi and Kujala, 2013)

The number of SAR missions per vessel in the simulation varies greatly: some vessels have many calls while others are expected to get very few SAR missions, see Figure 5.

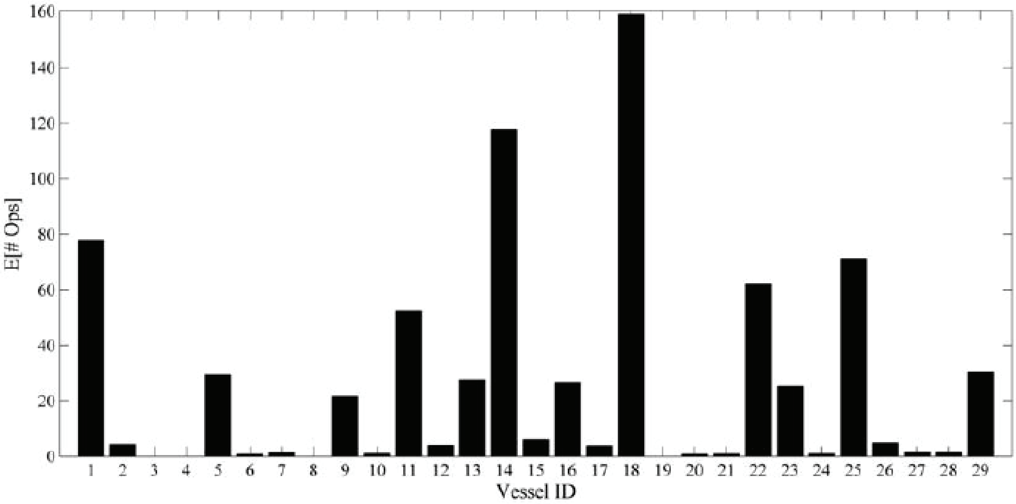


Figure 5 Expected number of SAR missions for different SRUs (Goerlandt, Torabihaghighi and Kujala, 2013)

The application of the extended sensitivity-uncertainty-bias framework, as presented in Goerlandt et al. (2014b), furthermore allows an evaluation of the elements of the analysis which are evidentially uncertain, biased and/or sensitive. Such uncertainty assessments are typically not performed in quantitative maritime risk assessment (Sormunen et al., 2014), but the analysis shows that uncertainty can have a large impact on the results. Not taking this uncertainty into account can lead to implementing ineffective or sub-optimal risk control options as well as potentially giving a false sense of security or risk to the decision-makers.

One weakness of the applied methodology is the need for a considerable amount of historic incident data, which has not been available for the Russian waters of the Gulf of Finland. A cross-border SAR response evaluation has thus not been possible.

2.3. Visual data mining of boating incidents with additional data

Sonninen (2014) analyzes maritime incident data to gain a better understanding of the conditions and causes of SAR missions in the Gulf of Finland (GoF). Parallel coordinate plots (PCPs), bivariate maps and multiform bivariate matrixes were used as analytic methods.

SAR missions are conducted around the clock and all year round but the incidents are heavily concentrated on the summer months, especially when the weather is clear. This is when recreational boats are most active, see Figure 6. The Finnish Lifeboat Institution (SMPS) reduces it activity for the winter season. During summer months there is more daylight, thus recreational boats are active longer into the evening. During good light conditions the SAR missions can reach several kilometers out to the sea but during evenings the recreational boats stay closer to the shore

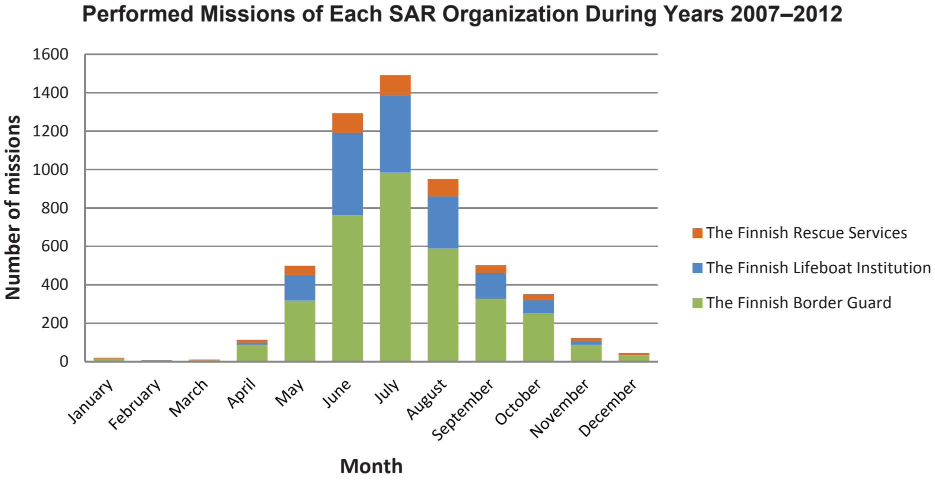


Figure 6 Mission performances during each month 2007–2012 (Sonninen, 2014).

For the Gulf of Finland, over 50 % of the SAR missions are performed in Helsinki or Espoo. The most common incidents are mechanical breakdowns (30 %) and groundings (15.8 %), see Figure 7. In 19 % of the cases the factor is unknown. 75 % of the SAR missions are targeted at motor boats and ~25 % at sailing boats. The motorboats were mostly small with a length of no more than 7 meters.

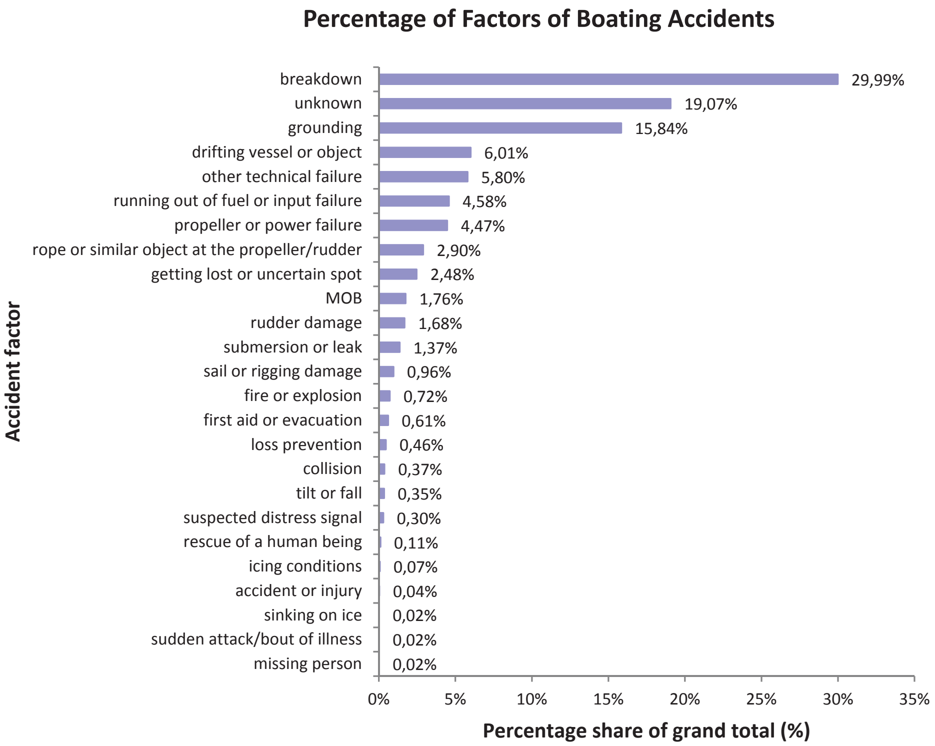


Figure 7 Factors leading to SAR missions (Sonninen 2014).

Looking at the weather conditions, the place with most SAR missions during high wave and wind warnings was the Western GoF, especially the Inkoo-Kirkkonummi region. The capital region had most SAR missions during high wave (2.5 m or higher) conditions. The Border Guard had the most long-range SAR missions and most missions under challenging weather conditions while the Rescue Services have their missions mostly close to land, SMPS being in between these two.

2.4. Development and application of maritime SAR simulation model

A first development for risk management of the voluntary SAR response system in Finland and Russia concerns the development of a discrete event simulation model for the SAR system. The model aims at providing strategic risk management decision support, by answering how many SRUs are in principle needed for a desired system performance (Torabihaghighi, 2012).

The rationale of this model is that the occurrence of a boating incident is a discrete-event simulation based on a data analysis of the SAR incident data. Subsequently, a Search and Rescue response unit (SRU) is assigned to the action, based on a simple criterion which minimizes the time at which the SRU becomes available for a new action. This demand-response system is simulated for all the incidents occurring in the considered sea area in a Monte Carlo simulation loop, from which a number of system performance indicators are derived. These include the number of missions each SRU performs, the travel time and the probability that a mission needs to be delayed due to the lack of available SRUs. The generic modeling rationale is shown in Figure 8, and a schematic overview of the SAR simulation model is shown in Figure 9.

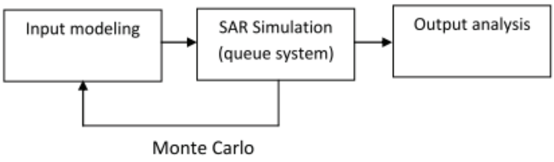


Figure 8 Generic overview of discrete-event system simulation modeling (Torabihaghighi, 2012).

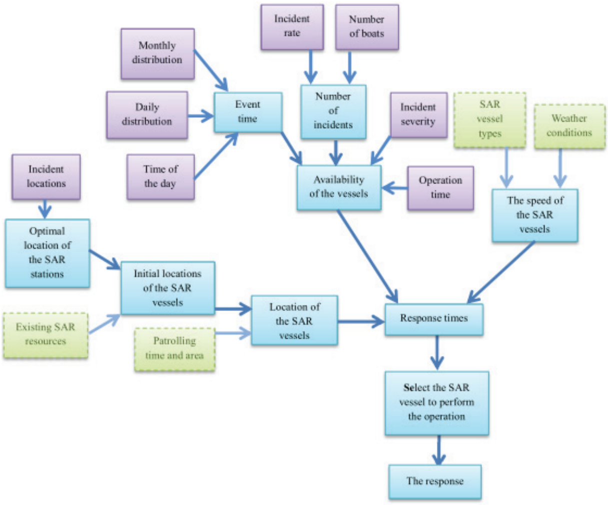


Figure 9 Flowchart of the SAR simulation model (Jemli, 2012).

As always the case in system simulation modeling, the quality of the results can only be as good as the quality of the input data and the model rationale. As for the model structure, the general process of the response of a single SRU to an incident location and the execution of the mission is quite well captured, although some simplifying assumptions are made. In the first version (Goerlandt et al., 2012; Jemli, 2012; Torabihaghighi, 2012), the influence of environmental conditions is omitted and the travel time is calculated based on a simple distance formula. In the second model version (Goerlandt et al., 2013), the influence of the wave height of the attainable SRU travel speed is accounted for, and a path planning algorithm is implemented to determine more realistic travel distances and travel times.

For the Finnish waters, input data is relatively good as much reliable SAR incident data is available, from which informative statistical input can be derived, see Figure 10 and Figure 11. For the Russian waters, no such data could be obtained, and a proxy had to be used through an analysis of AIS data for recreational vessels. This AIS data is very limited compared to the actual expected number of boats active in Russian sector (Deltamarin LTD, 2006; Jemli, 2012). Moreover, the AIS reliability of recreational vessels is questionable. Hence, the results for Russian waters should be considered in a more exploratory sense, providing only a rough indication of which stations would provide the best response capacity for SAR in the Russian waters of the Gulf of Finland for a future development of the Russian voluntary rescue services.

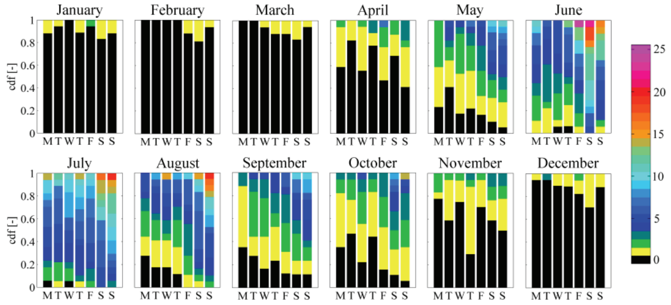


Figure 10 **Statistical analysis of number of SAR incidents in the Finnish Gulf of Finland per time period (Goerlandt et al., 2013).**

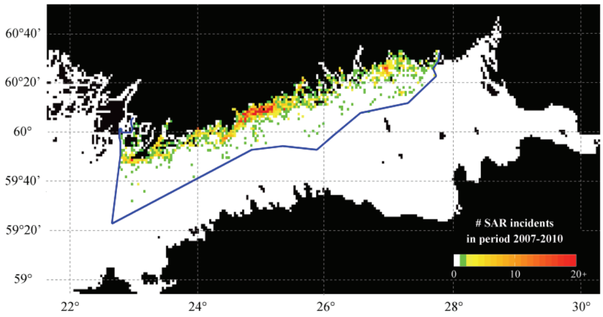


Figure 11 **Statistical analysis of number of SAR incidents in the Finnish Gulf of Finland by location(Goerlandt et al., 2013).**

The model output indicates that the response capacity of the Finnish waters in the Gulf of Finland is very satisfactory. In fact, the model indicates that some SRUs are not performing many missions. This can indicate that some SRUs may be reallocated to areas where response capacity is lacking. In contrast, the Russian voluntary SAR system, which is still under development, lacks capacity to provide an efficient SAR services in the whole Russian sector. In Jemli (2012), a set of alternate scenarios are investigated to guide decision making as to in which areas of the Russian sector the development of new SAR stations would be most effective.

As an overall conclusion of the model, it has been found that it is capable of providing generic insight in the performance of the SAR fleet. However, a large number of simplifications and assumptions are inherent in the model, and the results are only indicative of the real situation. Moreover, the use of the model is not straightforward, because of which a simpler, interactive tool for SAR planning has also been developed.

2.5. Visual data mining of SAR missions and environmental conditions

In her Master's thesis Venäläinen (2014) utilizes Geographical Information System (GIS) tools to support emergency planning in the Finnish Gulf of Finland.

The SAR response in the GoF is evaluated using four indicators; number of concurrent incident in certain areas, percentage of incident locations reached within certain time in different wave height conditions, percentage of incident locations reached with two units within certain time and percentage of high density areas reached within certain time. When we observe the study area the response, as evaluated with these indicators, is generally quite good. (Venäläinen, 2014)

When it comes to predefined SAR response times, SMPS does not have pre-defined reponse time goals. RAJA has a (non-binding) objective of reaching 90 % of incidents in no more than 45 minutes. SMPS can, however, easily reach the same goal apart from south-western wind of 14 m/s or more: Under these conditions 90 % of the incidents can already be reached in no more than 25 minutes.

The effect of wind on the response times is visualized in Figure 12. Wave heights due to 6 m/s second wind does not really affect the response time but a wind speed of 14 m/s already has a significant effect.

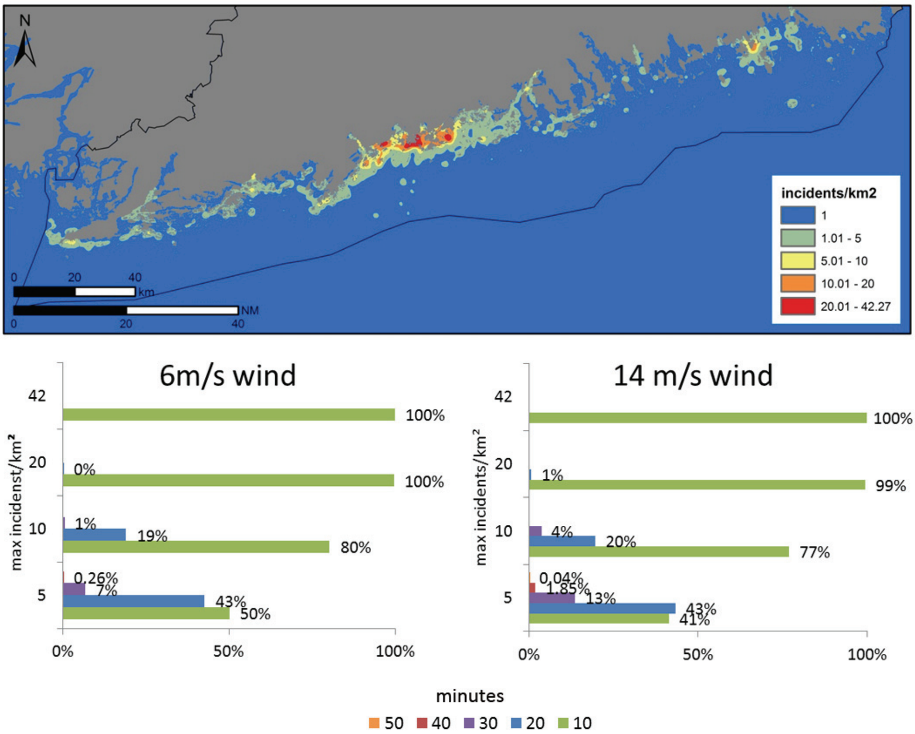


Figure 12 Incident density map and percentages of incident density classes reached within certain times. Mean values of modelled wave heights are used (Venäläinen, 2014).

3. Risk assessment for maritime transportation

The work performed related to risk assessment for maritime transportation is part of a long-term goal to develop a set of reliable methods for assessing risk of shipping in a maritime sea area. In such a setting, it is desirable to have methods both for assessing which sea areas present higher risk to navigation, and methods for assessing consequences in case accidents involving ships occur, both in open water and in ice.

Such information is useful for the planning of the oil spill response and for prioritizing protective measures for ecologically sensitive areas (COWI, 2011), and can identify locations where additional risk control measures may be put in place to reduce the risk (Pedersen, 2010; Rosqvist et al., 2002). The information of accident-prone areas can also be useful for consequence assessment for rare events such as passenger vessel collisions (Montewka et al., 2012a), by providing probabilities of scenarios under which such events can occur (Montewka et al., 2012b).

In the course of the project, it was found that there currently are no reliable methods for assessing which locations of a sea area are more prone to accidents, highlighting the need for further research toward reliable and valid methods. Despite the lack of reliable available models, where uncertainties are typically not elaborated upon (Sormunen et al., 2014), work has focused on the development of consequence models for assessing risk to two accident types which are of specific importance in the Gulf of Finland. A first model concerns the oil outflow from product tanker collisions, whereas the second model concerns the consequences of a collision with a RoPax vessel in a sea area. These scenarios are selected as they are considered among the most relevant accident scenarios in the Gulf of Finland. These models should be seen as elements in an integrative effort to develop a set of sub-models for a holistic assessment of the accident risk in the maritime transportation system in the Baltic Sea and the Gulf of Finland (Montewka et al., 2014; 2011).

Each of these studies is briefly introduced in the following sections.

3.1. Study on reliability and validity of ship collision risk analysis

A first study investigates the reliability and validity of ship-ship collision risk analysis (Goerlandt and Kujala, 2014). A range of methods has been presented in the technical literature to evaluate in which sea areas accidents are more likely. International organizations have made recommendations regarding suitable tools for risk analysis (IALA, 2009; IMO, 2010). However, it is important that risk assessment methods are valid, even if risk assessment cannot in general be expected to provide a reliable risk picture (Aven and Heide, 2009). In the context of risk assessment of maritime transportation, it is considered important to investigate the reliability of accident models in the maritime transportation system. In the work, three methods for evaluating ship-ship collision risk presented in the technical literature are applied to the Traffic Separation Scheme area of the Gulf of Finland. In particular, the methods by Goerlandt and Kujala (2011), Weng et al. (2012) and Qu et al. (2011) are investigated. The first applies traffic simulation and a collision candidate detection algorithm similar to the model by Pedersen (2010). The second uses data from the Automatic Information System (AIS) directly, along with a circular ship domain. The third also uses AIS data, along with a fuzzy quaternion ship domain presented by Wang (2010). The details of these methods are described in the respective publications and in Goerlandt and Kujala (2014).

The reliability of these methods was evaluated using criteria proposed by Aven and Heide (2009). A set of test cases was run for each method, systematically modifying model parameters and evaluating the effect on the assessment. In Figure 13, the areas in which the risk level is computed according to the three methods is shown.

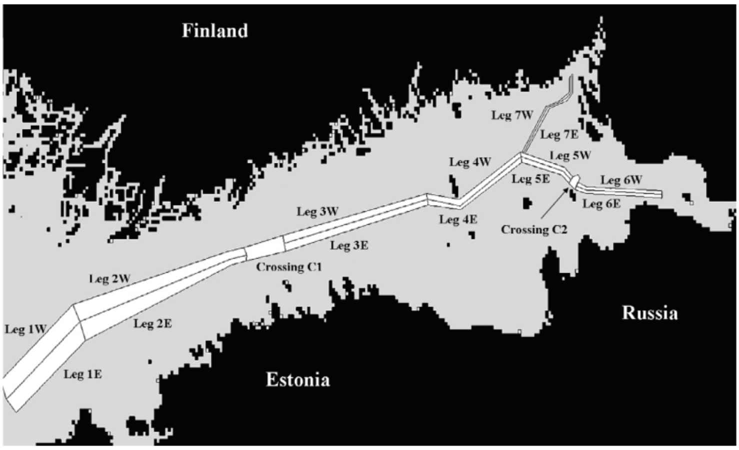


Figure 13 Overview of the considered areas in the Gulf of Finland (Goerlandt and Kujala, 2014)

In Figure 14, one of the main results of the study is shown. The figure shows the values of the risk metrics in each leg using a range of symbols, for the three methods and varying data sets. The scatterplots below the diagonal show pairwise comparisons between the risk metric according to two selected test cases. The numbers above the diagonal are statistical indicators showing how equal the two results are. In case of a perfect match between the two methods, i.e. in case the two methods identify the same sea areas as the most accident-prone areas, the dots below the diagonal should lay on a line and the statistical indicators should be 1.

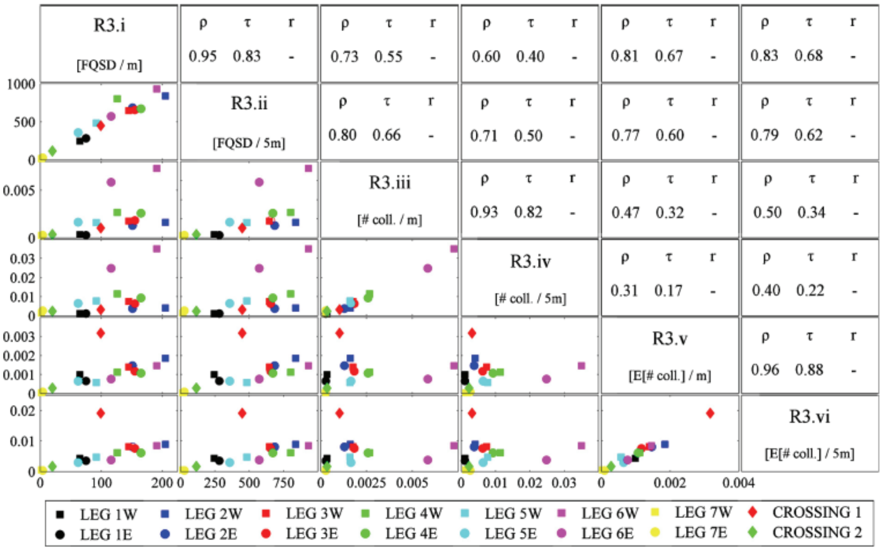


Figure 14 Results from the inter-methodological reliability tests, from (Goerlandt and Kujala, 2014)

It is however seen that this is not at all the case: all three methods identify different sea areas as most accident-prone. This low inter-methodological reliability raises questions concerning the validity of the methods. In terms of risk theory, the methods fail to address evidence uncertainties based on which the assessment is made. In particular, the definition of the ship-ship encounter from which the likelihood of a collision accident is derived, is based on rather poorly evidenced simplifications for all three methods. In conclusion, it is found that these currently available, state-of-the-art methods cannot provide a very trustworthy nor consistent picture of the collision risk in an open sea area. The results from this reliability and validity study have been further compared to a study aimed at spill response, as reported in the BRISK project (COWI, 2011). The model applied in the BRISK project is based on traffic flow analysis and has strong similarities to the model by Goerlandt and Kujala (2011) and the currently recommended tool by relevant authorities (IALA, 2009; IMO, 2010). The comparison, made in Goerlandt et al. (2014a) shows that the results from the four considered approaches are not well in line, supporting the earlier work even further.

While the immediate practical implications of this study are limited, important scientific conclusions can be drawn. First, there is a clear need for further research regarding reliable and valid maritime transportation risk models, which could be useful for rescue response fleet organization. Second, there is a need for actual models which could provide insight in the transportation risk. For the task related to a spatial assessment of oil outflows, it was decided that currently available models are too unreliable to use. Focus then has shifted towards developing a probabilistic oil spill consequence model and developing methodological improvements in risk assessment work, presented next.

3.2. A model for oil outflow from product tanker collisions

The assessment of the possible oil outflows in case of a merchant ship accident is of particular importance to the environmental protection and the emergency preparedness for oil spill response.. For this kind of maritime transportation risk assessment, several models have been developed. IMO (2003) has proposed a methodology for assessing the oil outflow from a reference tanker. This method suffers from weaknesses in that it is based on damage statistics of mainly single hull vessels and that the damage scenario generation is based on an unrealistic assumption of uncorrelated damage extent variables. Gucma and Przywarty (2008) report on a statistical model of oil outflow, based on historic accident data. Montewka et al. (2010) presented a simplified probabilistic model for oil outflow, rooted in the IMO-methodology. van de Wiel and van Dorp (2011) present a logistic regression oil outflow model for two tanker sizes operating in US waters, which links variables of the impact scenario with the oil outflow. The model is a significant improvement in maritime risk assessment, but is restricted by the predefined tank layouts to which the oil outflow is conditional.

In Goerlandt and Montewka (2014), a Bayesian Network model is presented for the accidental cargo oil outflow from product tankers involved in a collision. The choice for product tankers is due to the fact that these are the most prevalent tanker size in the Gulf of Finland, but the methodology can be applied also to other tanker sizes. For chemical tankers, see Sormunen et al. (2013; 2014).

The model used here integrates two main models: The first model is by Smailys and Česnauskis (2006), which is used to determine the tank sizes of vessels operating in the Gulf of Finland based on limited data available from the Automatic Information System (AIS) and tank layout data from IHS Maritime (2013). A series of parameters are used to estimate the tank sizes of typical product tankers, as illustrated in Figure 15(left).

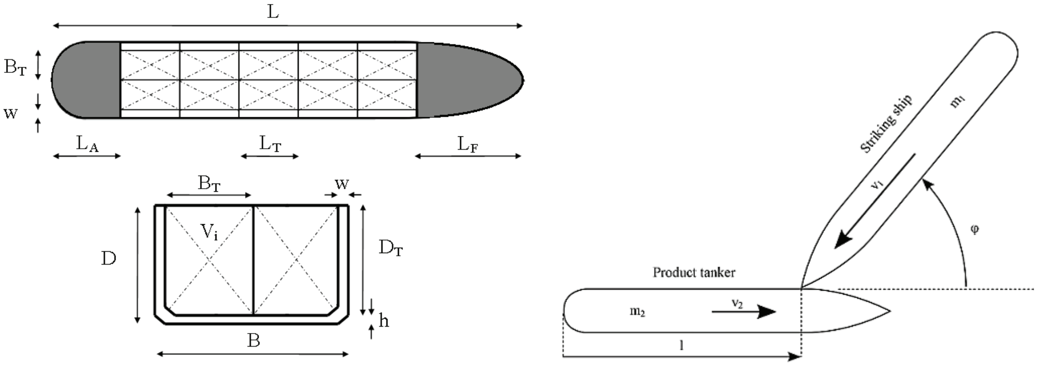


Figure 15 Definition of product tanker vessel layout and impact scenario (Goerlandt and Montewka, 2014)

A second is a model by van de Wiel and van Dorp (2011) is applied to estimate the hull damage extent conditional to the struck tanker's hull, conditional to the impact conditions. This logistic regression model is based on a large set of damage cases reported by NRC (2001) calculated using the model by Brown and Chen (2002). The model's main variables are illustrated in Figure 15(right). From the impact scenario variables, a set of predictor variables is derived, which are used in a regression model to determine the longitudinal and transversal damage extent. This damage extent is used to determine the compartments which are breached. The total volume of these tanks is assumed to be spilled.

These models are used to generate a large set of damage cases for a set of tanker layouts which are typically found in the Gulf of Finland. The simulated oil outflows for combinations of ranges of impact scenario variables are used to determine the parameters in the Bayesian Network. The final model is shown in Figure 16. It can be used to probabilistically assess the possible spill sizes when the impact conditions of a collision accident are given. In maritime risk assessment, an assessor can thus use the model to express uncertainty about the possible states of the input variables (Montewka et al., 2014). The presented network is built to be compatible with related models for clean-up cost of a spill (Montewka et al., 2013), environmental damage resulting from oil spills (Lecklin et al., 2011) and holistic models for maritime risk assessment (Montewka et al., 2014).

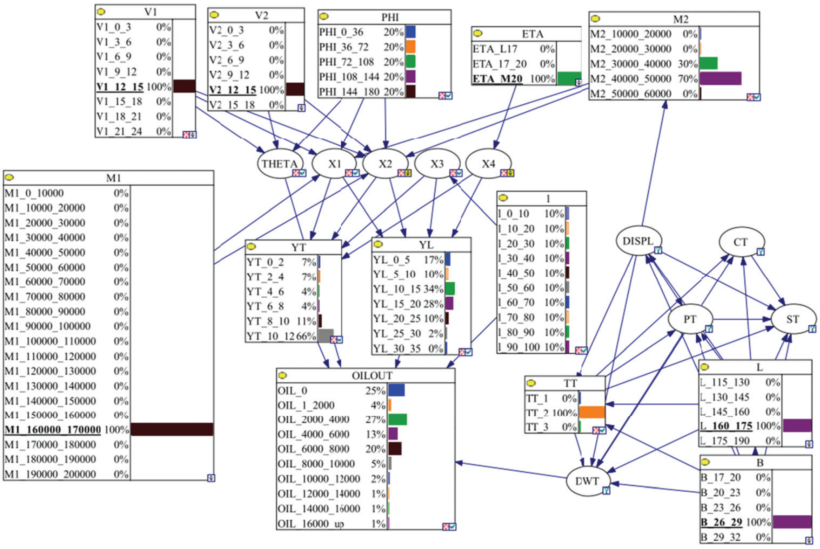


Figure 16 Bayesian oil spill model for product tanker collisions in open sea waters, from (Goerlandt and Montewka, 2014)

3.3. A model for assessing uncertainty of the consequences of a RoPax ship-ship collision

The unreliability of the maritime risk assessments leads to the consideration of new perspectives for describing risk, which is a current issue of discussion in the risk research literature (Aven and Zio, 2013). In many maritime risk assessment applications, uncertainty is not specifically addressed, making it difficult to assess which parts of the model can be considered accurate and which may need improvement (Sormunen et al., 2014). However, recently proposed risk perspectives consider uncertainty, rather than probability, the core of risk descriptions (Aven, 2013). Hence, tools are needed to assess and express these uncertainties, beyond the probabilistic assessments.

In Goerlandt et al. (2014), several such tools are introduced and applied to the RoPax collision model developed by Montewka et al. (2012a). The extended uncertainty assessment allows for a systematic scrutiny of the evidential support for the probability assignments in the nodes of the BN, both in terms of uncertainty and bias. This uncertainty/bias assessment is mapped alongside a sensitivity assessment of the BN, indicating to which nodes of the BN the outcome is most sensitive. The sensitivity-uncertainty-bias assessment thus provides insight into which model parts have a significant impact on the results and/or which are based on poor evidence.

Montewka et al. (2012a) present a Bayesian Network model for evaluating the consequences of a collision where a RoPax vessel is struck, which is a relevant scenario for SAR planning and response. The model integrates several engineering models for hull breach, flooding and capsizing, providing a probabilistic description of the time to capsize and the number of fatalities, conditional to conditions prevailing in the Gulf of Finland. The model layout is shown in Figure 17and is discussed in more detail in Montewka et al. (2014). While the risk model necessarily involves a number of assumptions and simplifications, the results in terms of the fatalities in such accidents corresponds reasonably well with statistical information from historic accidents.

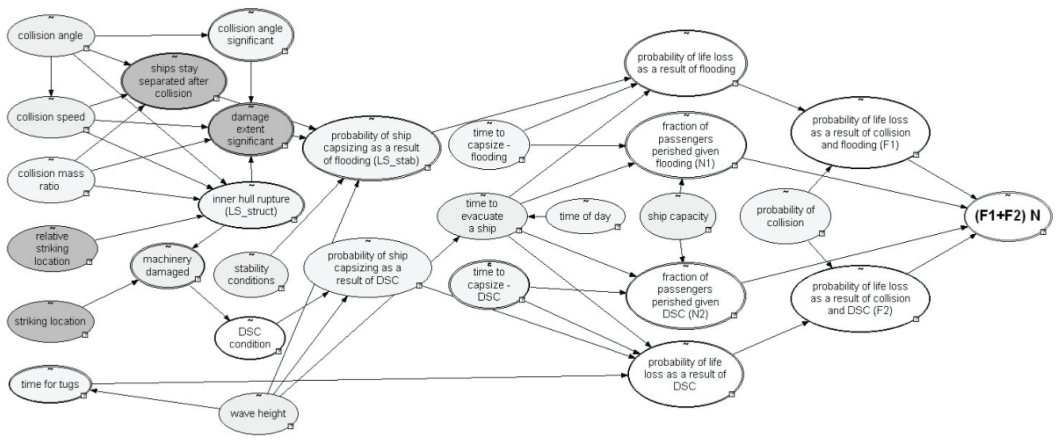


Figure 17 RoPax collision consequence model (Montewka et al., 2014)

The proposed extended evidence assessment methodology consists of two steps. In the first step, a sensitivity analysis is performed for the BN. For the sensitive nodes, a detailed evaluation of the evidence on which the node probabilities are based, is performed. This is done by establishing a

UB-score justification table, in which uncertainties and (when applicable) biases are identified and weighed against one another using a dual ordinal ranking method, as illustrated in Table 1.

Table 1 Uncertainty – bias score justification table

	Uncertainties due to model simplifications	**Score**	**Rank**
U1	Striking ship bulbous bow is assumed rigid, leading to uncertainty in the force-penetration curve: the bulb will deform and absorb some impact energy.	L	2
U2	Omission of forecastle structure of striking ship leads to uncertainty in force-penetration curves and required energy for inner hull rupture.	H	1
	Overall uncertainty score	**M-H**	
	Biases due to model simplifications	**Score**	**Rank**
B1	The inner hull rupture analysis is based on the midsection frame, i.e. the structurally weakest. This is a conservative assumption.	7	2
B2	Omission of forecastle structure is a very severe but conservative simplification: the forecastle structure will absorb some impact energy.	9	1
	Overall bias score	**7-9**	

In the second step, the overall uncertainty and bias scores for the model elements are subsequently aggregated in a SUB-matrix, which summarized the node sensitivities, uncertainties and biases for the entire model, as shown in Figure 18.

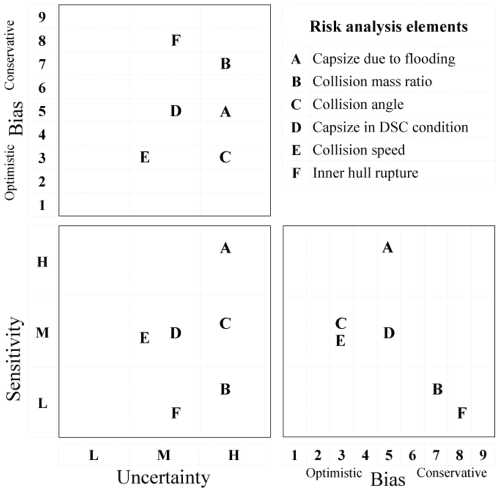


Figure 18 Sensitivity- uncertainty – bias matrix

The utility of this method is that it is for a user of the model or a decision maker relatively straightforward to assess the importance of uncertainties and biases in the background knowledge to which the BN is conditional. The visual SUB matrix tool quickly shows which model parts are most in need of improvement, whereas the UB-justification table provides supporting argumentation for placing the elements in their respective places in the SUB matrix. It allows a reviewer to understand the reasoning process of experts and analysts in developing the methods, improving transparency.

This methodology has been applied in the risk-informed SAR capability assessment by Venäläinen (2014), showing the applicability of the method to systematically assess potential weaknesses in the assessment, including their effect on the drawn conclusions.

4. Developments for risk assessment in winter navigation

A special feature of the Gulf of Finland is the annual ice cover which often constricts sailing to ice-breaker maintained channels during winter and early spring (Goncharov et al., 2014). This brings special challenges and risks with it as the ice channels i.e. restrict ship movement and bring them closer together than the ships would sail under open water conditions and also changing how the ships react to steering commands. In case of oil spills, the ice cover restricts and slows the spreading of oil slicks compared to open-water cases but make recovery much more difficult.

To better understand the effects of ice on the risk of maritime traffic in the Gulf of Finland, the following are investigated:

- Changes in forces that ships experience caused by sailing in ice channels
- Spreading of oil slick in ice channel

The results are briefly described as follows. For a more comprehensive description, see Goncharov et al. (2014) and Goncharov (2014).

4.1. A model for interaction of ships within navigable ice channel

During the ice cover period ships' hull experience increased loads due to the ice and have limited maneuverability, especially when forced to sail in ice channels. Reduced maneuverability increases the collision probability of ship collisions in encounter situations. The ice and ice floes in the channel also lead to situations where passing ships experience increased (and changing) side force and yawing moment during divergence.

In order to better understand this phenomenon and its effect on winter navigation safety, Goncharov et al., (2014) developed a mathematical model for vessel interaction in ice channel that contains ice floes. The model also can determine the additional ice loads to the vessels along with the side forces and yawing moments as a function of vessel dimensions, velocities, ice channel size and the broken ice in the channel. Conceptual analysis of experimental data gave base for assuming that side force and yawing moment on ship hull appear to depend on ice floe concentration near hull boards and difference of ice resistance that arise as result of narrowing of water surface between hull and borders of channel and between hulls during ship-ship passage. The overtaking vessel was simulated by means of narrowing of the ice channel width during passage. The ice concentration *s* increases in inverse proportion to the beam distance between ships in comparison with ice concentration between reverse board and edge of channel Increase of ice concentration increases ice loads on ship hull that result in initiation of additional ice resistance *R*, side force *F* and yawing moment *M* during passing.

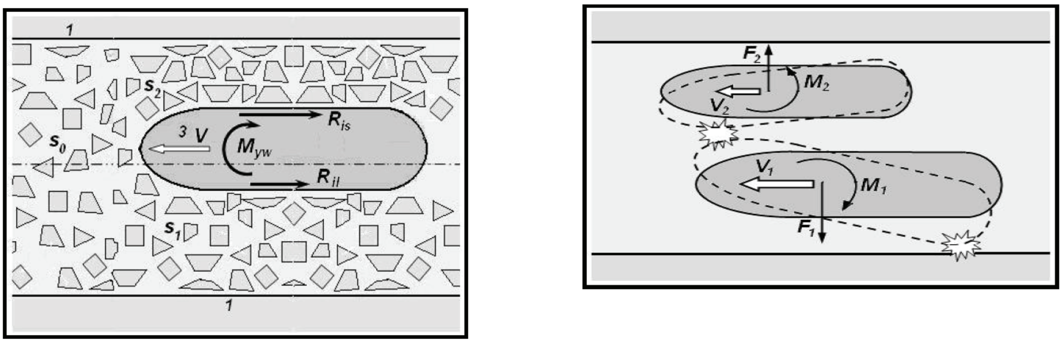


Figure 19 Yawing moment arising under vessel motion near ice channel boarder (left) and tendency of yawing of vessels of during passing (right) (Goncharov et al., 2014).

The developed conceptual model allows to parameterize the forces *R* and *F* as well as the yawing moment *M* by the difference of ice loads on left and right boards of the ship. Loads caused by moving apart ice floes by ship hull *N* and their friction on hull plating *S* produce main contribution to ice resistance of ship and can be transform into elementary ice resistance *dR*, side force *dF* and yawing moment *dM,* see Figure 20.

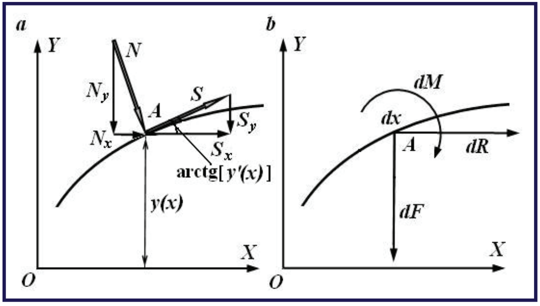


Figure 20 Effect of ice floes on hull plating (*a*) and elementary ice loads (*b*) (Goncharov et al., 2014).

By integration along ship hull, the following formulas have been developed that give possibilities to simulate the additional ice resistance *R(t)*, side force *F(t)* and yawing moment *M(t)* as functions of time during overtaking (opposite motion) for various ice conditions, width of channel and distance between ships' hulls.

$$R(t)=\gamma_{Ice}\sqrt{b_{Ice}\,h_{Ice}}\int_{0}^{\xi(t)}\left[k_1(t,x)-k_{10}\right]\,y_1(x)\left[k_{fr}-y_1'(x)\right]dx,$$

$$F(t)=\gamma_{Ice}\sqrt{b_{Ice}\,h_{Ice}}\int_{0}^{\xi(t)}\left[k_1(x)-k_{10}\right]\,y_1(x)\left[1-k_{fr}\,y_1'(x)\right]dx,$$

$$M(t)=\gamma_{Ice}\sqrt{b_{Ice}\,h_{Ice}}\int_{0}^{\xi(t)}\left[k_1(t,x)-k_{10}\right]y_1(x)\,x\left\{1-\left[y_1'(x)\right]^2\right\}dx.$$

Figure 21presents variation of coefficients of additional ice resistance C_R, side force C_F and yawing moment C_M affecting on overtaking ship during this maneuver.

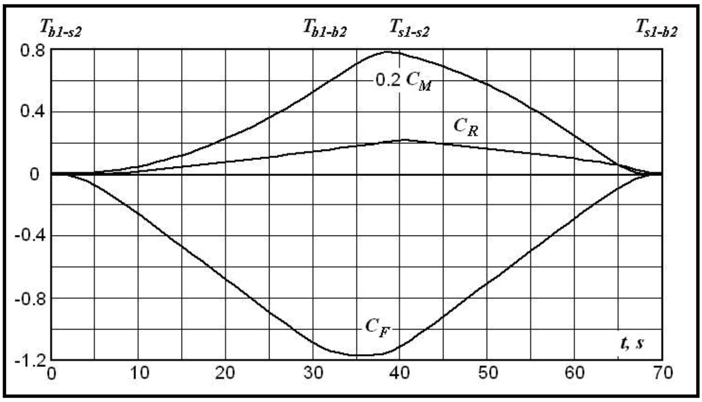


Figure 21 Variation coefficients of loads on ship hull during overtaking within navigable ice channel (Goncharov et al., 2014).

Simulation of interaction of ship in process of overtaking reveals that side force effects in direction on the border of ice channel and yawing moment effects on overtaken ship. As result, possibilities of collisions arise: by bow with overtaken ship and by stern with channel borders, as it is presented in Figure 19 (right).

The results of the model were compared to earlier ice tank experiments on a qualitative level, confirming the difference in ship-ship hydrodynamic interaction in ice channel compared to open water. It is possible to apply model to define the safe regimes of maneuvering within the navigable ice channel (speed and distance between ships) in dependence on the ship dimensions and ice conditions. Thus the developed model can be used in training bridge personnel to better understand and predict their ship's behavior when sailing in ice channels. Understanding and being able to predict better ship motion under challenging conditions can increase safety by decreasing the frequency of situations where ships do not react to the steering as expected.

4.2. Simulation of crude oil spreading within the navigable ice channel

Risk caused by potential oil spills at sea have for decades been a concern of risk analysts, officials, mariners, shipping companies, environmental activists and ordinary people alike: The potential consequences on marine ecosystems can be catastrophical. To better understand how oil spills spread under ice conditions, Goncharov (2014) presents a model for oil spill propagation in ice channel. The presence of ice walls limits how the oil will spread and decrease how fast the oil spreads: Both the side walls as well as ice in the channel itself will cause the oil slick to experience greater friction compared to an open-water scenario. On the other hand, ice can complicate the collection of spilled oil, making recovery efforts much more difficult. In order to simulate oil spills it was necessary to solve two tasks: first, to develop a simplified model of the channel that describes the content and dimensions of ice floes in channel and, second, to develop an analytical model for the process of crude oil flow among ice floes and borders of channel.

Figure 22 presents a real view of ice channel behind the icebreaker. It shows how the broken ice in the navigable ice channel is divided into ice floes with various forms and dimensions as well as brash ice. Statistical analysis of ice channel pictures shows that dimensions of ice floes behave log-normally and their form is largely trapezoidal.

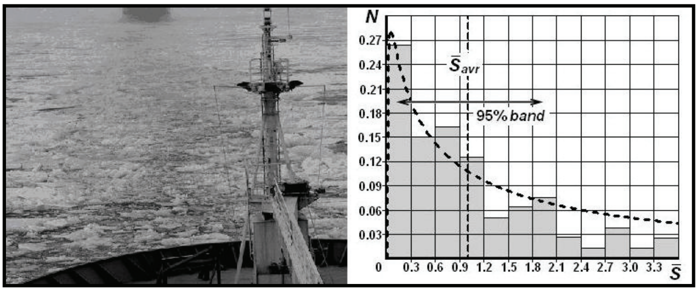


Figure 22 Picture of the ice channel and lognormal distribution of ice floe sizes (Goncharov, 2014).

The model of ice content of navigable channel describes the water surface bounded by borders of channel with floating separate ice floes and oil in between these. Aggregate of brash ice was presented as separate ice floes, see Figure 23.

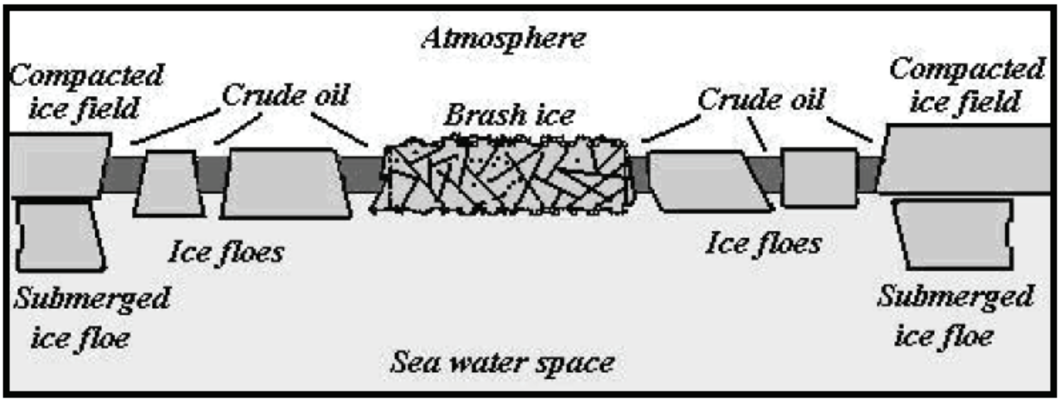


Figure 23 Cross-section of ice channel with spilled crude oil (Goncharov, 2014),

The resistance for oil flowing in the channel consists of the friction between oil and the water surface as well as the friction between the oil and lateral surfaces of ice floes and channel borders. The gravitational-viscous stage of oil spreading was studied and differential equation were developed. The following solution for spreading volume *Q* spilled crude oil within ice channel was derived.

$$t = k_{IC}\, R^{7/3} \left(R^{0.5} + k_{IO} \frac{\nu_p^{0.5}}{\nu_w^{0.5}} \frac{\overline{P}_{VF}\, Q}{f_{ice}^{0.5} B_{VP}^2} \right)^{2/3} \left[\frac{4g}{c_f} \nu_w^{-0.5} \frac{\rho_w - \rho_p}{\rho_w} \frac{Q^2}{B_{VP}^2} \right]^{-2/3} .$$

This model makes it possible to calculate the time *t,* when the edge of oil film reaches the distance *R* from point of accidental oil spill in dependence on properties of oil, ice conditions and dimensions of channel. The spreading velocity decreases the more ice there is in the channel. Furthermore, i.e. the shape of the ice floes has an effect – rectangular ice floes slow the spread more than trapezoidal ice floes. Figure 24 presents an example of oil spill spreading simulation: spreading of 100 m^3 crude oil as a function of time for various ice concentrations *S* in the ice channel.

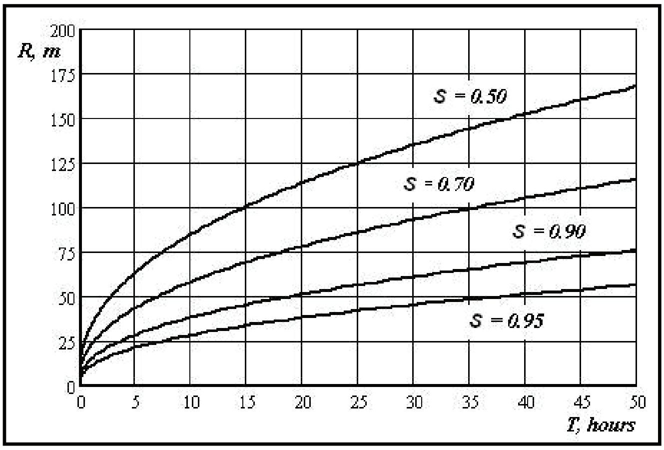


Figure 24 Length of oil slick (*R*) as a function of time (*T*) and the ice concentration (*S*) in a 20 m wide ice channel (Goncharov, 2014),

The model can be used i.e. to better predict oil spill spreading in ice channels so that the clean-up operation can be better planned ahead: authorities will better know how far the oil slick will progress before cleanup-vessels can reach the accident site. However, in order to model the friction caused by the sidewalls of the ice channel experiments will need to be conducted to obtain the necessary empirical factors.

5. Conclusions

In this report the SAR incidents in the Finnish GoF were thoroughly analyzed using different statistical, visual and GIS analytical tools. The aim was to gain a better understanding of the nature of these incidents and how effectively they are dealt with at the moment as well the results could be used to improve SAR. When it comes to the response time of the Finnish Search and Rescue Units (SRUs), this is generally speaking this is found to be good, except under very strong wind conditions, though some long response times do occur. The SAR missions are mostly caused by recreational motorboats during summertime and good light conditions. Geographically the heaviest concentration of SAR missions happens outside Helsinki and Espoo. The harshest conditions for SAR missions in terms of high waves and strong wind is in the Western Gulf of Finland.

The consequences of ship collisions with tankers and RoPax –vessels were also evaluated. The uncertainties, sensitivities and biases of the models used in this evaluation process was mapped out and it was found that much work needs still to be done in order to have models that can reliably estimate ship collision frequency and consequences. A particular challenge in this aspect is the fact that modeling ship-ship collisions requires linking multiple models together which leads to the uncertainty or sensitivity of that model to propagate throughout the system, in effect affecting all the consequent steps of the collision analysis. Furthermore, using different assumptions regarding collision variables - such as angle and velocity – leads to different results in terms of collision damage.

The model of ship interaction in ice channels allows for a greater understanding of a phenomenon where ships respond differently compared to what would happen in an open water scenario. This can be used to train bridge personnel to gain a better understanding of their vessel, thus decreasing the probability of a ship-ship collision in ice channel due to e.g. unexpected response by the ship to steering made on the bridge. Furthermore, the oil spread model presented here can be used to improve planning of oil spill clean-up operations as it allows to predict how far the oil slick will spread in the ice channel until clean-up vessels can reach the accident site.

Acknowledgements

The report received funding from RescOp, which is funded from the South-East Finland – Russia ENPI CBC 2007-2013 Programme, which is co-funded by the European Union, the Russian Federation and the Republic of Finland. The Joint Managing Authority for the Programme is the Regional Council of South-Karelia.

The project is also partially co-financed by the implementing partners: Kotka Maritime Research Association is the projects' lead partner and the project consortium consists of altogether 10 partners, 3 from Finland and 7 from Russia. The partners are Kymenlaakso University of Applied Sciences, Aalto University School of Engineering, The Finnish Lifeboat Institution, Admiral Makarov State Maritime Academy, Saint-Petersburg State Marine Technical University, Saint-Petersburg State Unitary Enterprise PILARN, Committee for Nature Use Environmental Protection and Ecological Safety, St. Petersburg State University Division of International Baltic and Arctic projects, Central Marine Research & Design Institute Ltd and Regional Public Organisation "Russian Voluntary Maritime Rescue Society of Kronstadt"

Associated partners supporting the projects' objectives and participating in the implementation as experts are St.Petersburg Search and Rescue Service, St.Petersburg State Small Vessel Inspection (Ministry of Emergency Russia), Maritime Rescue Coordination Center SPb Sea Port Administration (Ministry of Transport Russia), Emercom of Saint-Petersburg, Finnish Border Guard, Finnish Environment Institute, Vsemirnyi fond prirody (WWF Russia), Baltic Fund for Nature and WWF Finland.

Appendix

In this appendix, the references to the materials produced that aim at risk assessment of maritime SAR are listed. The materials are accessible also via the website http://www.merikotka.fi/rescop/.

Report on visualization and analysis of Finnish SAR missions

Venäläinen E, Sonninen M. 2013. Suomen meri- ja järvipelastustehtävät: Karttoja ja analyyseja vuosien 2007-2012 tehtävistä. Aalto-yliopiston julkaisusarja. Unigrafia Oy, Helsinki, ISBN 978-952-60-5326-4, p. 439. Available online: http://urn.fi/URN:ISBN:978-952-60-5327-1

Visual data mining of SAR missions and environmental conditions

Sonninen, M, 2014. Visual data mining techniques applied to SAR data. Master's Thesis, Aalto University.

Capability assessment of the Finnish SAR in the Gulf of Finland

Venäläinen, E, 2014. Geographical information systems supporting maritime search and rescue planning- Evaluating voluntary emergency response in the Gulf of Finland. Master's Thesis, University of Helsinki.

Maritime SAR response simulation tool

Goerlandt, F., Torabihaghighi, F., Kujala, P., 2013. A model for evaluating performance and reliability of the voluntary maritime rescue system in the Gulf of Finland. Presented at the 11th International Probabilistic Safety AsAnnual European Safety and Reliability Conference, Amsterdam, The Netherlands, pp. 1–6.

Goerlandt, F., Torabihaghighi, F., Ståhlberg, K., Jemli, J., Kujala, P., 2012. Simulation model for evaluation of effectiveness of maritime SAR services, in: 11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference. Presented at the ESREL2012 / PSAM11, Curran Associates Inc., Helsinki, Finland, pp. 5508–5517.

Jemli, J., 2012. Maritime Search and Rescue in the Russian part of the Gulf of Finland, MSc Thesis, School of Engineering. Aalto University, Espoo, Finland.

Torabihaghighi, F., 2012. Constructing a model for search and rescue in Gulf of Finland, MSc Thesis, School of Science. Aalto University, Espoo, Finland.

Risk assessment of maritime transportation – open water

Goerlandt, F., Kujala, P., 2014a. On the reliability and validity of ship–ship collision risk analysis in light of different perspectives on risk. Saf. Sci. 62, pp. 348–365.

Goerlandt F., Montewka J. 2014. A Bayesian Network Model for Accidental Oil Outflow in Double Hull Oil Product Tanker Collisions. Presented at the 12th International Probabilistic Safety Assessment and Management Conference (PSAM12), 22-27 June, Hawaii, USA.

Goerlandt F., Montewka J., Kujala P. 2014. Tools for an extended risk assessment for RoPax ship-ship collision. Presented at the Second International Conference on Vulnerability and Risk Analysis and Management (ICVRAM) & Sixth International Symposium on Uncertainty Modelling and Analysis (ISUMA), 13-16 July, Liverpool, UK.

Goerlandt, F., Montewka, J., Kujala, P., 2014. On the need for next generation maritime transportation risk models - a case study concerning reliability of ship collision risk assessment. Presented at the International Workshop on Nautical Traffic Models, Wuhan, China, pp. 1–10.

Risk assessment of maritime transportation – winter navigation

Goncharov, V., 2014. Simulation of crude oil spreading within the navigable ice channel. Unpubl. Manuscr.

Goncharov, V., Klementieva, N., Sazonov, K., 2014. Interaction of ships within navigable ice channel. Accepted for publication in J. Shipp. Ocean Eng.

Goncharov V. Klementieva N. and Sazonov K., 2012. Interaction of ships under navigation in ice conditions, Proceedings of NAV 2012, 17th International Conference on Ships and Shipping Research. Naples, Italy.

Goncharov V. Klementieva N. and Sazonov K., 2013. Interaction of ships under traffic within navigable ice channel, In: Proceedings of the 22nd International Conference on Port and Ocean Engineering under Arctic Conditions, POAC'13, Espoo, Finland. Paper No. 58.

References

Aven, T., 2013. Practical implications of the new risk perspectives. Reliab. Eng. Syst. Saf. 115, pp. 136–145.

Aven, T., Heide, B., 2009. Reliability and validity of risk analysis. Reliab. Eng. Syst. Saf. 94, pp. 1862–1868.

Aven, T., Zio, E., 2013. Foundational issues in risk assessment and risk management. Risk Anal.

Brown, A.J., Chen, D., 2002. Probabilistic method for predicting ship collision damage. Ocean. Eng. Int. 6, pp. 54–65.

COWI, 2011. BRISK - Sub-regional risk of spill of oil and hazardous substances in the Baltic Sea.

Deltamarin LTD, 2006. Maritime Search and Rescue on the Eastern Gulf of Finland. Kotka.

Goerlandt, F., Kujala, P., 2011. Traffic simulation based ship collision probability modeling. Reliab. Eng. Syst. Saf. 96, pp. 91–107.

Goerlandt, F., Kujala, P., 2014. On the reliability and validity of ship–ship collision risk analysis in light of different perspectives on risk. Saf. Sci. 62, pp. 348–365.

Goerlandt, F., Montewka, J., 2014. A Bayesian Network model for accidental oil outflow in double hull oil product tanker collisions. Presented at the 12th International Probabilistic Safety Assessment and Management Conference, Hawaii, USA.

Goerlandt, F., Montewka, J., Kujala, P., 2014a. Tools for an extended risk assessment for RoPax ship-ship collision. Presented at the Second International Conference on Vulnerability and Risk Analysis and Management (ICVRAM) & Sixth International Symposium on Uncertainty Modelling and Analysis (ISUMA), Liverpool, UK.

Goerlandt, F., Montewka, J., Kujala, P., 2014b. On the need for next generation maritime transportation risk models - a case study concerning reliability of ship collision risk assessment. Presented at the International Workshop on Nautical Traffic Models, Wuhan, China, pp. 1–10.

Goerlandt, F., Torabihaghighi, F., Kujala, P., 2013. A model for evaluating performance and reliability of the voluntary maritime rescue system in the Gulf of Finland. Presented at the 11th International Probabilistic Safety AsAnnual European Safety and Reliability Conference, Amsterdam, The Netherlands, pp. 1–6.

Goerlandt, F., Torabihaghighi, F., Ståhlberg, K., Jemli, J., Kujala, P., 2012. Simulation model for evaluation of effectiveness of maritime SAR services, in: 11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference. Presented at the ESREL2012 / PSAM11, Curran Associates Inc., Helsinki, Finland, pp. 5508–5517.

Goncharov, V.K., 2014. Simulation of crude oil spreading within the navigable ice channel. Unpubl. Manuscr.

Goncharov, V.K., Klementieva, N.Y., Sazonov, K.E., 2014. Interaction of ships within navigable ice channel. Accepted for publication in J. Shipp. Ocean Eng..

Gray, D.L., Canessa, R.R., Keller, C.P., Dearden, P., Rollins, R.B., 2011. Spatial characterization of marine rcreational boating: exploring the use of an on-the-water questionnaire for a case study in the Pacific Northwest. Mar. Policy 35, pp. 286–298.

Gucma, L., Przywarty, M., 2008. The model of oil spills due to ship collisions in Southern Baltic Area. TransNav Int. J. Mar. Navig. Saf. Sea Transp. 2, pp. 415–419.

IALA, 2009. IALA Recommendation O-134 on the IALA risk management tool for ports and restricted waterways.

IHS Maritime, 2013. Maritime Insight & Information.

IMO, 2003. Revised interim guidelines for the approval of alternative methods of design and construction of oil tankers. Regulation 13F(5) of Annex I of MARPOL 73/78 Resolution MEPC.110(49).

IMO, 2010. Degree of risk evaluation. SN.1/Circ.296.

Jemli, J., 2012. Maritime Search and Rescue in the Russian part of the Gulf of Finland, MSc Thesis, School of Engineering. Aalto University, Espoo, Finland.

Lecklin, T., Ryömä, R., Kuikka, S., 2011. A Bayesian network for analyzing biological acute and long-term impacts of an oil spill in the Gulf of Finland. Mar. Pollut. Bull. 62, pp. 2822–2835.

Montewka, J., Ehlers, S., Goerlandt, F., Hinz, T., Kujala, P., 2012a. A model for risk analysis of RoPax ships - the Gulf of Finland case, in: 11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference. Curran Associates Inc., New York, pp. 5544–5553.

Montewka, J., Ehlers, S., Goerlandt, F., Hinz, T., Tabri, K., Kujala, P., 2014. A framework for risk assessment for maritime transportation systems - A case study for open sea collisions involving RoPax vessels. Reliab. Eng. Syst. Saf. 124, pp. 142–157.

Montewka, J., Goerlandt, F., Kujala, P., 2012b. Determination of collision criteria and causation factors appropriate to a model for estimating the probability of maritime accidents. Ocean Eng. 40, pp. 50–61.

Montewka, J., Krata, P., Goerlandt, F., Mazaheri, A., Kujala, P., 2011. Marine traffic risk modelling - an innovative approach and a case study. Proc. Inst. Mech. Eng. Part O J. Risk Reliab. 225, pp. 307–322.

Montewka, J., Ståhlberg, K., Seppala, T., Kujala, P., 2010. Elements of risk analysis for collision of oil tankers, in: Risk, Reliability and Safety. Taylor & Francis Group, London, pp. 1005–1013.

Montewka, J., Weckström, M., Kujala, P., 2013. A probabilistic model estimating oil spill clean-up costs - A case study for the Gulf of Finland. Mar. Pollut. Bull. 76, pp. 61–71.

Neuvonen, M., Sievänen, T., Korhonen, K., 2009. Rannikkoalueen virkistyskäytön kysyntä (Metlan työraportteja No. 116).

NRC, 2001. Environmental performance of tanker designs in collision and grounding, Special report 259. National Research Council.

Pedersen, P.T., 2010. Review and application of ship collision and grounding analysis procedures. Mar. Struct. 23, pp. 241–262.

Pegler, K., 2004. A marine recreational vessel reconnaissance system using Ikonos Imagery (No. 226). University of New Brunswick - Geodesy and Geomatics Engineering, Fredericton, New Brunswick, Canada.

Qu, X., Meng, Q., Li, S., 2011. Ship collision risk assessment for the Singapore Strait. Accid. Anal. Prev. 43, pp. 2030–2036.

Rosqvist, T., Nyman, T., Sonninen, S., Tuominen, R., 2002. The implementation of the VTMIS system for the Gulf of Finland - a FSA study, in: Proceedings of the RINA International Conference on Formal Safety Assessment. Royal Institution of Naval Architects, London, pp. 1–14.

Räsänen, J., Järvi, T., Mäkelä, K., Rytkönen, J., Hentinen, M., Hänninen, S., 2005. Veneilyn määrä ja taloudelliset vaikutukset Suomessa (No. 5/2005), Merenkulkulaitoksen julkaisuja. Merenkulkulaitos, Helsinki, Finland.

Smailys, V., Česnauskis, M., 2006. Estimation of expected cargo oil outflow from tanker involved in casualty. Transport 21, pp. 293–300.

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. Proc. Inst. Mech. Eng. Part M J. Eng. Marit. Environ. DOI: : 10.1177/1475090213515640.

Sormunen, O.-V., Ehlers, S. and Kujala, P., 2013. Collision consequence estimation model for chemical tankers, Proc IMechE, Part M: Journal of Engineering for the Maritime Environment 227 (2), pp. 98 - 106.

Torabihaghighi, F., 2012. Constructing a model for search and rescue in Gulf of Finland, MSc Thesis, School of Science. Aalto University, Espoo, Finland.

Van de Wiel, G., van Dorp, J.R., 2011. An oil outflow model for tanker collisions and groundings. Ann. Oper. Res. 187, 279–304.

Wang, N., 2010. An intelligent spatial collision risk based on the quaternion ship domain. J. Navig. 63, pp. 733–749.

Weng, J., Meng, Q., Qu, X., 2012. Vessel collision frequency estimation in the Singapore Strait. J. Navig. 65, pp. 207–221.

Venäläinen, E., Sonninen, M., 2013. Suomen meri- ja järvipelastustehtävät: Karttoja ja analyyseja vuosien 2007-2012 tehtävistä, Aalto-yliopiston julkaisusarja. Unigrafia Oy, Helsinki, Finland.

Aalto-ST 6/2014

ISBN 978-952-60-5725-5 (pdf)
ISSN-L 1799-4896
ISSN 1799-4896
ISSN 1799-490X (pdf)

Aalto University
School of Engineering
Department of Applied Mechanics
www.aalto.fi

BUSINESS +
ECONOMY

ART +
DESIGN +
ARCHITECTURE

SCIENCE +
TECHNOLOGY

CROSSOVER

DOCTORAL
DISSERTATIONS