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Utilizing geographic information systems tools for risk-informed maritime search and rescue performance evaluation

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Key words: maritime SAR, GIS, risk-informed performance evaluation, maritime safety, incident analysis, incident duration

Abstract

In many sea areas there is significant recreational activity, with many sailing vessels and motor boats navigating, especially in coastal areas. Search and Rescue (SAR) organizations ensure the safety of people at sea, and are relatively frequently called to perform rescue or assistance missions to people in distress. Apart from the importance of adequate operational planning and training, rescue organizations benefit from establishing a robust, effective and cost-efficient response system. Risk-informed capacity planning can serve as a decision-support tool for determining the number and location of the required search and rescue units (SRUs). The purpose of this paper is to present such a risk-informed approach, which combines analysis of historic accident and incident data of recreational boating with information derived from Geographic Information System (GIS) methods. The method is applied to a case study focusing on the risk-informed capacity evaluation of the voluntary search and rescue services in the Finnish part of the Gulf of Finland. Results indicate that the response performance for recreational boating incidents is very good in most areas.

Introduction

In many sea and inland water areas, significant recreational activity exists, especially during the summer season. While fishing, kayaking, sailing and other water-based recreation are important functions of a maritime area, they may induce a risk to human life. Incidents and accidents resulting from boating activity occur relatively frequently, requiring the operation of robust, effective and cost-efficient maritime search and rescue (SAR) services. Apart from the importance of adequate operational procedures and planning, high-quality training and suitable equipment, SAR organizations can benefit from strategic capacity planning. Such analyses assess the demand level of rescue activity in different geographical areas, and evaluate the response capacity in light of this demand. Such a process of strategic risk-informed maritime SAR planning has received relatively little attention from the responsible authorities and organizations. This paper contributes to this field through presenting a methodology relying on Geographic Information Systems (GIS) tools and a set of risk-indicators. The method is applied to a case study for the Finnish sea areas of the Gulf of Finland, focusing on the performance of the rescue fleet operated by the Finnish Lifeboat Institution. The study area is shown in Figure 1, in which the location of the rescue stations is indicated.

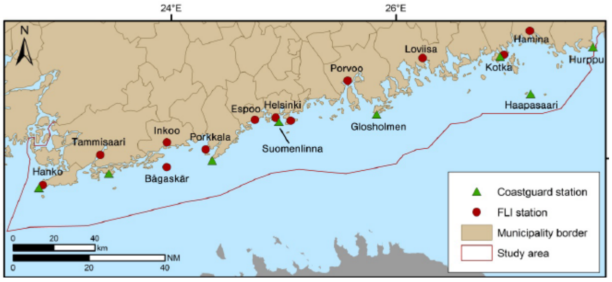

Figure 1. Definition of the study area, with indication of rescue stations of Finnish Lifeboat Institution and Finnish Border Guard

The rest of the paper is organized as follows. In the section *Related work and contribution*, an overview of related work is presented. In the section *Risk-theoretical and methodological basis*, the risk-theoretical and methodological basis for the risk-informed response planning method is introduced, while the section *Risk and response performance indicators* presents the indicators used to assess the spatial and temporal risk levels, as well as the metrics used to evaluate the response performance. The section *Risk indicators: SAR incident data analysis* shows the results of the SAR incident data analysis, acting as risk indicators. The section *Performance indicators: GIS-based analysis* presents results from the response performance, based on GIS methods. In the section *Risk-informed SAR performance evaluation*, a risk-informed performance evaluation is shown. The approach is discussed in the section *Discussion* and the section *Conclusions* concludes the paper.

Related work and contribution

Various approaches have been proposed for evaluating the performance of a SAR response system, or for planning its organization. Pelot et al. (1998; 2006) developed an incident-based model for the demand for rescue services, and a coarse spatial risk analysis based on questionnaire and incident data. Deltamarin (2006) performed a trend analysis of maritime activity and a coarse spatial response analysis for the eastern Gulf of Finland. Koldenhof and Tak (2013) present the results of a risk analysis of SAR in the North Sea area, based on a calculation of the number of potential persons at risk in different sea areas, in relation to the available SAR response capacity. Li (2006) applied mathematical optimization of the maximum coverage problem to the strategic positioning of SAR units in Canadian east coast waters. Azofra et al. (2007) developed a gravitational model to evaluate the suitability of locating rescue vessels in a given location. Norrington et al. (2008) introduced Bayesian network modeling as a tool to evaluate the reliability of SAR operations. Goerlandt, Torabihaghighi and Kujala (2014) proposed a data-driven discrete event simulation model for evaluating the performance and reliability of a SAR system. Siljander et al. (2015) investigated the feasibility of cost-based GIS methods to evaluate the response times for Search and Rescue Units (SRUs) in different meteorological conditions.

The current method and application is closely linked to the work in Pelot et al. (1998; 2006) and Koldenhof and Talk (2013), but it advances this literature mainly by the application of more advanced GIS-tools for determining the response performance in different weather conditions, and by the application of a more elaborate set of specific risk and performance indicators than in the previous work in this field.

Risk-theoretical and methodological basis

Risk definition and perspective

In the maritime application area, a great variety of risk definitions and approaches to risk analysis currently co-exist (Goerlandt & Montewka, 2015). As the lack of terminological clarity may complicate risk communication, it is important to provide clarity about some key terminology, and on the perspective taken to describe risk.

In the current work, risk is understood as referring to the possible but uncertain occurrence of a situation where something of human value is at stake. The risk concept is used to focus on the possible occurrence of future events, which are possible but may or may not occur.

To make statements about this possible occurrence, use is made of risk indicators. These are quantitative or qualitative measures of a characteristic of the SAR demand and SAR response system, which are used as a proxy for the occurrence of events and/or consequences. Indicators can also be used to inform about the system states relevant for providing insight into under which conditions the events occur, i.e. to provide insight in the SAR demand level and the relevant conditions to consider (Goerlandt & Montewka, 2015; Davies at al., 2006). These are constructed based on a given background knowledge (BK), which can constitute data, judgments, etc. The risk indicators can be used to qualitatively rank the risk in different sea areas. We can write (where "~" means "is described by"):

$$R \sim \{RI_k | BK\},\ k = 1 \ldots N \tag{1}$$

where RI_k is the k-th risk indicator, and N the total number of indicators. In the current application, the risk indicators focus on the SAR demand, and are determined mainly based on incident data analysis.

Indicators of response performance

The SAR response performance is defined in terms of a number of goals (target levels) set by the responsible organization, relevant for achieving the organization's aims. In the current application to SAR services, the focus is on safety goals on a strategic planning level.

To make statements about the performance, use is made of performance indicators. These are quantitative of qualitative characteristics of the SAR response system in relation to the SAR demand, which are used as a proxy for the overall performance quality. These are constructed based on a given background knowledge (BK), which constitutes data, models and judgments. The performance indicators can be used to qualitatively and argumentatively rank the risk in different sea areas. We can thus write:

$$R \sim \{PI_j | BK\}, \quad j = 1 \ldots M \qquad (2)$$

where PI_j is the j-th performance indicator, and M the number of indicators. In the current application, the performance indicators assess the SAR response quality in relation to the SAR demand.

Risk and response performance indicators

The selection of risk indicators is based on expert judgment of operational personnel from the Finnish Lifeboat Institution (FLI). These are listed below.

RI_1: Trends in number of incident occurrences
RI_2: Prevailing meteorological conditions
RI_3: Spatial distribution of incidents
RI_4: Temporal distribution of incidents
RI_5: Types of incidents
RI_6: Object to respond to in incidents
RI_7: Number of concurrent incidents

The selection of performance indicators is also based on expert judgment of operational personnel from the Finnish Lifeboat Institution (FLI). Some PIs are defined with the help of RIs, in particular RI_2, the prevailing weather conditions. These are listed below.

PI_1: Response time with 6 m/s winds
PI_2: Response time with 14 m/s winds
PI_3: Response time with two search and rescue units
PI_4: Time to area coverage

Risk indicators: SAR incident data analysis

In this section, the analyzed results of the available incident data are shown. This data has been made available by the Finnish Border Guard (FGB), the Finnish Lifeboat Institution (FLI) and the Finnish Rescue Services (FRS), and covers the years 2007–2012. Details about the data can be found in Venäläinen (2014).

RI_1: Trends in number of incident occurrences

The yearly number of incidents is shown in Figure 2. Using a trend testing technique proposed by Kvaløy and Aven (2005), it is found, with 95% confidence, that there is a negative trend in the number of incident occurrences in the Gulf of Finland area. However, with an average of about 1150 incidents per year, it is clear that SAR response organization is an important aspect of maritime safety.

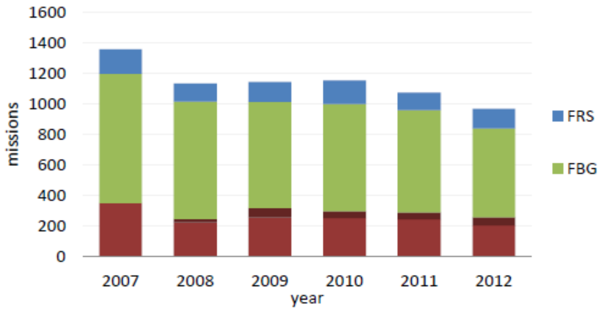

Figure 2. Trend in number of incident occurrences in the study area, data 2007–2012

Also, the downward trend implies that using the historic data as a source of evidence to plan the strategic SAR demand and SAR planning for future conditions will likely lead to a conservative characterization, which is acceptable from a safety point of view.

RI_2: Prevailing meteorological conditions

One important aspect for SAR planning is the meteorological conditions under which the operations can be expected to occur. In terms of SAR response, it has been found that the wave height and wind direction are the main determining factors for the operability and attainable speed for the search and rescue units (SRUs). Meteorological conditions were studied using weather data available from the Finnish Meteorological Institute (FMI), see Venäläinen (2014) for details.

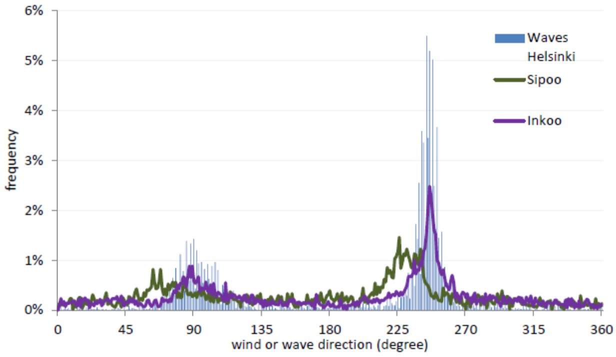

Figure 3. Prevailing wave and wind directions during recorded SAR incidents, data 2007–2012

Figure 3 shows the prevailing wave directions at the Helsinki wave buoy, located ca. 25 km south from Helsinki, and the wind directions at measurement stations in Inkoo and Sipoo, located west and east from Helsinki, respectively. The wave and wind conditions are determined at the start time of the SAR incidents available in the data. It is seen that there is a reasonable correspondence between wave and wind conditions, and that eastern, western and south-western winds are the dominant winds in the area.

Based on a questionnaire among operators of FLI, the operability limits and attainable speed for the SRUs can be approximated, based on the wave heights (Venäläinen, 2014). In the application of the GIS-methods for calculating the performance indicators, the wave heights are determined conditional to the wind speeds. Thus, apart from information about the wind direction, wind speeds need to be determined as well. Based on information in Hänninen at al. (2003), it is found that for the Gulf of Finland area, winds have an average of ca. 6 m/s with a plausible maximum of ca. 14 m/s, see Figure 4.

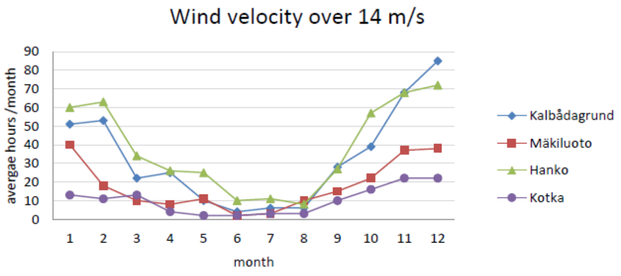

Figure 4. Wind observations from four stations in Gulf of Finland, data from 1996–2001. Edited from Hänninen at al. (2003)

Based on this information, six scenarios are selected, representing average and plausible maximum wind conditions during SAR operations in the Gulf of Finland. These scenarios are used in the application of the GIS-methods for determining the performance indicators in terms of the response times in the section *Performance indicators: GIS--based analysis*, and are summarized in Table 1.

Table 1. Wind scenarios for GIS-application in response performance analysis

	Wind scenarios WS_i			Wind scenarios WS_i	
	Direction	Speed [m/s]		Direction	Speed [m/s]
WS_1	east	6	WS_4	west	14
WS_2	east	14	WS_5	south-west	6
WS_3	west	6	WS_6	south-west	14

RI_3: Spatial distribution of incidents

The spatial distribution of incidents is shown in Figure 5, which is visualized using the ArcMap Density Toolset. It is seen that the density is highest in the Helsinki capital region, extending to the Porkkala peninsula and to Sipoo. Densities are also higher near the Kotka-Hamina sea area in the eastern part of the study area, and near Hanko in the west. Most incidents occur very close to the shore, with distances under 1 nm totaling ca. 95% (Venäläinen, 2014).

The spatial analysis is used to determine the response times to the incidents under the various wind scenarios of Table 1, using the GIS methods in the section *Performance indicators: GIS-based analysis*. The density analysis is also used to assess the response performance to high-density incident areas.

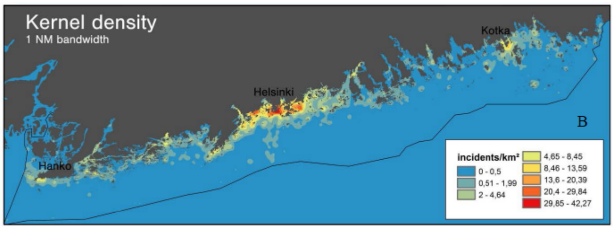

Figure 5. Spatial density of SAR incidents in study area, data from 2007–2012, kernel density 1 nm bandwidth

RI_4: Temporal distribution of incidents

Another element in determining the risk of SAR incidents is the temporal distribution of incidents. This is shown in Figure 6. The SAR demand is very low during the winter season, and exclusively handled by FBG. FLI and FRS start operations in the ice-free season, and are most active during the summer months, extending to the late autumn season. Focusing on the capability needs for the FLI, this information shows that the operability of the SRUs of the FLI should suffice for the meteorological conditions for these seasons.

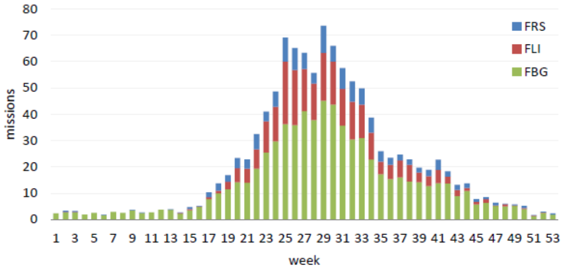

Figure 6. Temporal distribution of SAR incidents in the study area, data from 2007–2012

Comparing the demand level of Figure 6 with the wind observations of Figure 4, it is seen that the wind scenarios of Table 1 for the performance evaluation are reasonable.

RI_5: Types of incidents

The incident types of the incidents handled by FLI are shown in Figure 7. It is seen that most missions are assistance, e.g. towing vessels to shore or assistance with motor failure. Following commercial or preventive missions, Search and Rescue missions are also important mission types. Ambulance missions, environmental response and firefighting are relatively rarely operated by FLI. The main reason for FLIs focus on assistance missions is that the FBG, as the responsible response organization, more frequently executes search and rescue missions, while the FRS in relative terms focus more on the environmental response missions (Venäläinen, 2014).

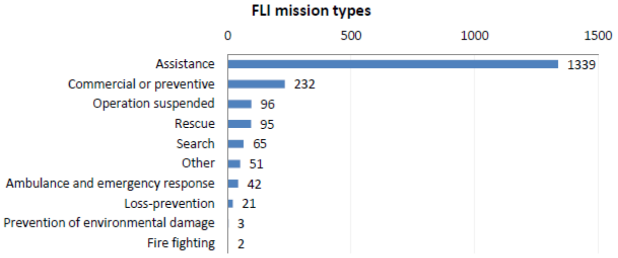

Figure 7. SAR incident types in missions executed by FLI, data from 2007–2012

In the performance evaluation in the section *Risk-informed SAR performance evaluation*, this information is not explicitly used, but it can provide some insight into the equipment needed onboard SRUs.

RI$_6$: Object to respond to in incident

Figure 8 shows the object of the FLI missions, i.e. the type of craft or target the FLI response fleet has responded to in the study area. It is seen that the predominant target type consists of pleasure vessels, of which most are small motorboats (< 7 m). Sailing vessels and larger size motor boats (7–15 m) are also important targets. Other types of recreational water units are less frequent. Furthermore, relevant targets are persons (e.g. in man over board situations), with other target types less frequently found.

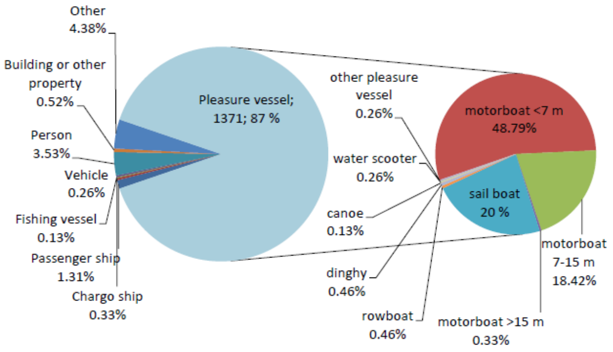

Figure 8. Objects of FLI missions in study area, data from 2007–2012

This information is not used as such in the performance assessment, but the target type and size can be useful e.g. for planning training scenarios and for understanding the SRU equipment needed to deal with the target types.

RI$_7$: Number of concurrent incidents

For strategic planning purposes, one important issue concerns how many incidents can be considered to occur simultaneously. This has direct repercussions on the number of SRUs needed for adequately covering the SAR demand.

To analyze this, the time between incidents and the incident duration is applied. In the data, only the incidents recorded by FLI had a recorded duration of the mission. The analysis in Figure 9 shows that about 90% of the missions are finalized within 4 hours, which is taken as a conservative value to the calculation of the number of concurrent incidents in all data (FLI, FBG and FRS).

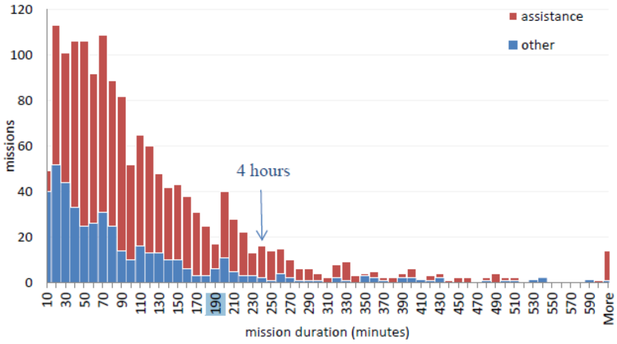

Figure 9. Distribution of incident duration in missions executed by FLI, data from 2007–2012

The number of concurrent incidents in different sub-areas of the study area is shown in Figure 10, using a procedure described in Venäläinen (2014). It is seen that according to the calculations, in most sea areas, the probability of simultaneous incidents is negligible above four incidents, whereas in the Helsinki metropolitan area (Espoo-Helsinki), the number of simultaneous incidents can be as high as eight.

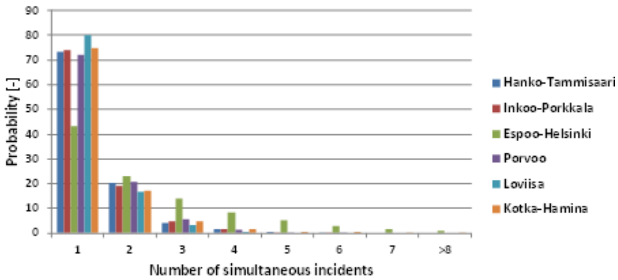

Figure 10. Probability of concurrent incidents in different sub-areas of the study area, data from 2007–2012

Performance indicators: GIS-based analysis

Response time calculation using GIS tools

For calculating the response times of the FLI fleet to the incidents, use is made of Geographic Information Systems methods. At the basis of the calculation lies the current fleet organization in terms of the number and types of vessels in the different FLI-stations shown in Figure 1. The configuration of the FLI fleet is shown in Table 2.

Table 2. FLI fleet organization, status 06.2014

	AV	PV_1	PV_2	PV_3	PV_4	PV_5	PR
Hamina		1			1		
Bågaskär			1	1			
Porvoo	2		1	1			
Espoo			1	1			
Inkoo					1		
Kotka	1		1			1	
Tammisaari			1	1			
Loviisa	1	1			1		
Helsinki	1		1			1	
Porkkala	1		1			1	
Hanko			1				1
MP 1	1						1

The method is based on cost-distance modeling, using a rasterization of the study area. Cost-distance modeling essentially calculates the shortest path from one point on the map to another point, using ArcMap software. In the current application, the cost raster is specific to each SRU class, as these have different capabilities to operate in different wave conditions. Hence, a speed-dependency is introduced in the cost raster, which is dependent on the wave height. Wave heights in the sea area are calculated for each of the wind scenarios (WS_1 to WS_6) from Table 1. This is done using a wind fetch based wave model proposed by Rohweder et al. (2012), implemented in ArcMap software.

Details about the procedure can be found in Siljander et al. (2015). A schematic outline of the response time calculation procedure is shown in Figure 11, while the results for the response time mapping for a selected wind scenario are shown in Figure 12.

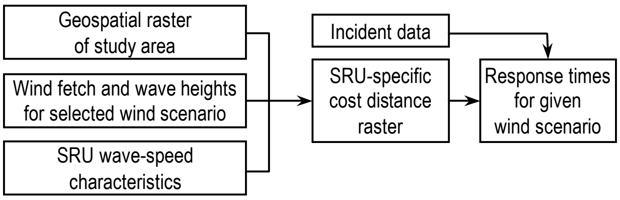

Figure 11. Outline of response time calculation procedure

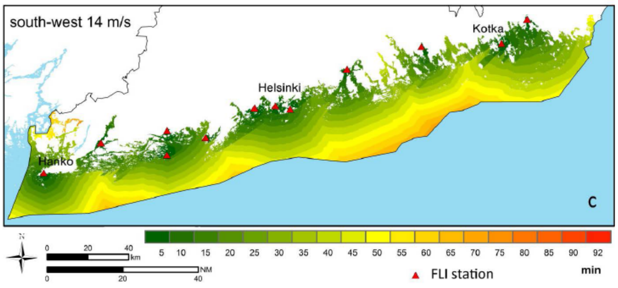

Figure 12. Response times for the study area, wind scenario WS_6, based on SRUs vessels of FLI

PI_1 and PI_2: Response time with 6 m/s and 14 m/s winds

The response times for the averaged wind scenarios WS_1, WS_3 and WS_5 (6 m/s) and WS_2, WS_4 and WS_6 (14 m/s) are overlaid with the incident density map. Results are given in Figure 13, where the response time distributions to different areas with varying incident density levels are shown.

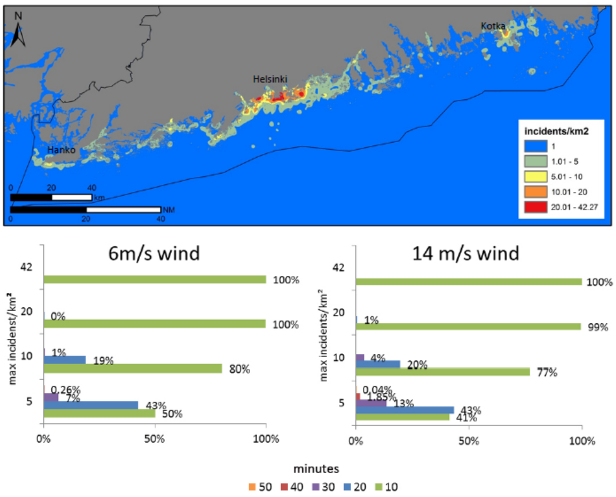

Figure 13. Response time evaluation for FLI fleet, averaged wind scenarios, data from 2007–2012

It is seen that all high-density incident areas are reached within less than 10 minutes measured from the time the SRU departs. For lower density incident areas, the response times are typically within 20 minutes, but some low-density areas can be reached only within 30 or even 40 minutes. The results are very similar for both averaged wind scenarios, the more severe 14 m/s based scenarios having slightly longer response times.

PI_3: Response time with two search and rescue units

Another important performance indicator concerns the response time to incidents with two SRUs. While in current practices FLI performs missions with a single SRU, there is an operational development to perform missions with two SRUs. The analysis is performed using the procedure of Figure

11, with the additional constraint that the area is considered covered only when two SRUs have reached the site.

The results indicate that, when only using SRUs operated by FLI, many of the incident areas are well covered with two units. The area between Porvoo and Loviisa (between Helsinki and Kotka), as well as the area around Hanko cannot however be reached by FLI response units. In contrast, the areas with high incident densities are well covered by FLI units, as is clear by comparing Figure 14 with Figure 15. Overall, about half of the incident sites in the study area can be reached by two units in 20 minutes, whereas about 80% of the sites can be reached in 30 minutes.

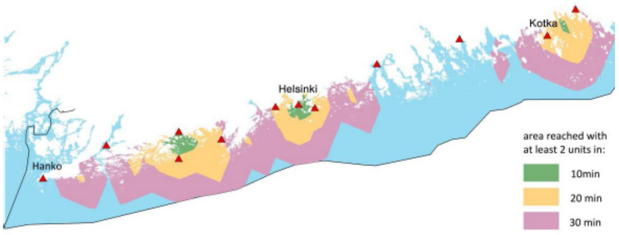

Figure 14. Area reached with two SRUs from FLI, in different times

Table 3. Incident sites covered by two SRUs from FLI using maximum unit speed, data from 2007–2012

Minutes	Number of incidents covered	P [%]	Cumulative P [%]
10	1163	18.9	18.9
20	2110	34.2	53.1
30	1794	29.1	82.2

PI$_4$: Time to area coverage

A final performance indicator concerns the time needed to cover the entire response area. While the FLI does not have legal requirements or the need to cover the entire sea area within a given time, it is useful to know in what time frame SRUs could first arrive on the scene in various parts of the study area. This is useful information e.g. for the case that incidents occur in locations not found in historic data.

The results show that in average wind conditions (6 m/s), the entire area can be covered by at least one SRU in 45 minutes. In severe wind conditions, this figure drops to ca. 70%, with the entire area covered only in ca. 90 min. This clearly shows the important influence of the wind and wave conditions to the response capacity. As most of the incidents occur near coastal areas, which are more sheltered from winds and waves, the response time to incident locations does not show a similar important influence, as seen in Figure 13.

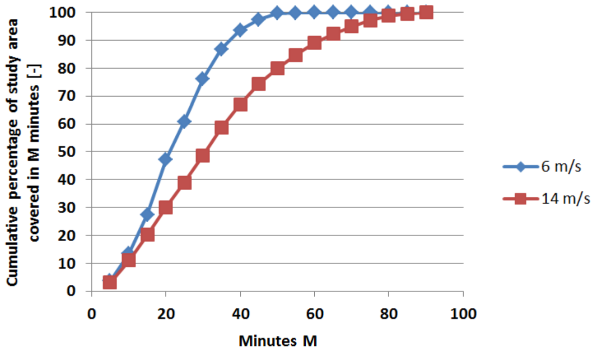

Figure 15. Response times for the study area, averaged wind scenarios for 6 m/s and 14 m/s, based on SRU vessels of FLI

Risk-informed SAR performance evaluation

As an overall performance evaluation, the performance indicators of the section *Performance indicators: GIS-based analysis* are summarized using a qualitative scale in Table 4.

Table 4. Performance evaluation based on indicators, for different sub-areas of study area

		PI$_1$	PI$_2$	PI$_3$
Kotka-Hamina	FLI	3	3	4
	FLI & FBG	5	5	5
Porvoo-Loviisa	FLI	2	2	1
	FLI & FBG	4	4	3
Helsinki-Espoo	FLI	5	4	4
	FLI & FBG	5	5	4
Inkoo-Porkkala	FLI	4	3	5
	FLI & FBG	5	5	5
Hanko-Tammisaari	FLI	4	3	3
	FLI & FBG	5	4	4

Notes: PI1, PI2 and PI3 as defined in section *Risk-theoretical and methodological basis* B

5: excellent | 4: very good | 3: good | 2: adequate, but could be enhanced | 1: does not meet target

It is seen that for the most part, the performance of the FLI meets the demand level very well. Improvements are possible especially in the Porvoo-Loviisa area, when only considering the FLI response fleet. When the response fleet of the FBG is also accounted for in the response evaluation, it is seen that the capacity meets the demands very well to excellently in all areas.

Discussions

Uncertainty analysis for the presented case study

In maritime risk analysis, the consideration of uncertainty has been given relatively little attention (Goerlandt & Montewka, 2015). However, assessing uncertainty is important, as uncertainties beyond the risk and performance evaluation may alter the decision making. An uncertainty assessment may also provide insight into which elements should be given further attention for refining the method, and/or to look for additional information.

An uncertainty assessment is made by considering the evidence base underlying the risk-informed performance evaluation of Table 4. The purpose of this evidence assessment is to take a critical look into the underlying evidence for the analysis, reflecting on the inaccuracy in data and methods, and on the type of assumptions and judgments made in the processing.

The underlying rationale of a method proposed in Goerlandt, Montewka and Kujala (2014) is used for this purpose, which looks into the uncertainty, bias and sensitivity of elements underlying the analysis. For each indicator, a number of aspects of the calculation procedure are critically inspected. The uncertainty (U) for each factor is rated (Low-Medium-High), or its bias (B) assessed (Conservative-Neutral-Optimistic). The overall assessment also includes a judgment on the sensitivity of the results to the evidential uncertainties and biases. The interpretation of the ratings is, for reasons of brevity, not shown here, but can be found in Goerlandt, Montewka and Kujala (2014). In principle, a justification for each of the assessments can be provided but, for reasons of brevity, this is omitted in this paper.

Table 5. Assessment of uncertainty, bias and sensitivity of the evidence underlying the performance evaluation

Response times to incident locations in different wave conditions		
	Aspect of calculation procedure	*Score*
	Unit speed in different wave heights	U-H
	Other SRU decelerating factors	U-M
	Wave height calculation	B-C
	Duplicate incidents in data	B-C
	Incident locations	B-N
	Overall	U-M | B-C | S-L
Response times for incident locations with two units		
	Aspect of calculation procedure	*Score*
	Other SRU decelerating factors	U-M
	Wave height calculation	B-C
	Incident locations	B-N
	Excluded incidents	B-C
	Overall	U-M | B-C | S-L

The analysis is performed in Table 5, and shows that all three indicators involve medium uncertainty, but are believed to be conservatively biased. The sensitivity of the uncertainties and biases to the resulting indicator values is judged to be low. Hence, according to this assessment, the indicator values can be considered adequate for assessing the performance of the SAR system.

Reflections on the proposed method

In the previous sections, an approach for calculating performance indicators has been shown. GIS-tools are used, in particular wind fetch and wave height calculation and cost-distance modeling. By making use of SRU class specific speed profiles, the capability of the entire fleet has been determined for a set of plausible wind scenarios.

Compared to earlier proposed SAR response methods and applications (Pelot, 2006; Deltamarin, 2006; Koldenhof and Tak, 2013), the use of the GIS tools allows for far greater detail in the response time calculation. This approach can thus provide deeper insight into the attained service levels in various wave environments. The ability to account for SRU class specific capabilities can provide insight into the vessel types required to operate in a certain geographical area to attain an envisaged service level. The detailed response time calculations allow (at least in principle) a demonstration of compliance with legal requirements which may be set by national authorities, e.g. that the entire SAR area should be covered in a given time. In the study area of the presented case study, the wave conditions are not particularly challenging for maritime response, with wave heights rarely exceeding 3 m. The benefits of the method are likely to be greater in areas where maritime response is more frequently hampered by higher wave heights, e.g. in open sea areas.

Despite the methodological refinement, certain challenges exist, which should be highlighted. First, while the GIS tools provide detailed results, their application is quite time-consuming. Second, the risk and performance indicators as applied in the proposed method require collected SAR incident data for analysis. While the risk indicators can in principle also be identified using expert judgment, the data availability may be challenging in other sea areas. Third, the GIS methods as available in current ArcGIS software have a number of drawbacks for modeling maritime response times, see Siljander at al. (2015) for a more in-depth discussion.

Future work

While the proposed method constitutes a contribution to the SAR response evaluation literature, several directions for future work can be identified.

First, work could focus on improving the wave models underlying GIS software. As discussed in Siljander et al. (2015), this is one of the greatest limitations of using GIS-tools for maritime cost-distance modeling. Even though the evidence assessment of Table 5 indicates that this leads to a low sensitivity and conservative estimates for the study area in the case study, this may not be so for other areas.

Second, the evaluation of the performance in Table 4 is in its present form rather coarse. More advanced mathematical methods could be applied to weight and rank the performance in different sub areas.

Third, the method could be applied further to not only evaluate the performance of the current configuration, but also to study alternative SRU configurations. Such an assessment could be used to find a proper balance between the attained SAR performance level and the costs for operating the system. While Table 4 shows that the current SAR configuration in the Finnish part of the Gulf of Finland performs excellently in terms of safety performance. However, safety comes at a cost, and alternative, cheaper configurations could lead to a comparable safety performance level, allowing for cost-saving in public expenditures.

Finally, it is an area of future research to combine the SAR evaluation for boating activity with the SAR demands from merchant traffic. While boating incidents occur frequently, merchant vessels much more rarely need evacuation. More research is needed on how the requirements of these two target systems (recreational and merchant maritime traffic) can be integrated for strategic maritime SAR planning.

Conclusions

In this paper, a method has been shown to evaluate the existing SAR capacity based on the demand level, i.e. a risk-informed approach to performance evaluation. The method relies on SAR incident data, meteorological and SRU performance data to derive a number of risk indicators. They provide insight into various elements of the system, particularly in terms of the demand for SAR services. The performance evaluation is carried out using calculated response times, derived from GIS tools. The influence of the wind and wave conditions to the response effectiveness has been accounted for through a wave- and speed-dependent cost-distance calculation procedure.

A case study is performed, which focuses on the Finnish waters of the Gulf of Finland, and on the performance of the FLI fleet in particular. It is found that the existing capacity for the most part meets the demand very well or even excellently, especially when the FBG fleet is also accounted for. While not studied further, the method may be applied to disinvest SRUs in the area, i.e. to reduce costs by taking certain SRUs out of service, while maintaining a good balance between SAR demand and capacity. The method can also be applied to explore different fleet configurations in terms of response performance.

While the method has certain limitations, several directions for future research have been identified. It is hoped that the presented method can lead to further developments for maritime SAR performance evaluation and planning.

Abbreviations

B: Bias | C: Conservative | FBG: Finnish Border Guard | FLI: Finnish Lifeboat Institution | FRS: Finnish Rescue Services | GIS: Geographic Information System | H: High | L: Low | M: Medium | N: Neutral | O: Optimistic | S: Sensitivity | SAR: Search and Rescue | SRU: Search and Rescue Unit | U: Uncertainty | WS: Wind Scenario

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