

# Risk level in peacetime Swedish naval operations

## Meta lessons identified

*av Hans Liwång*

### Resumé

2010 ändrade marinen definitionen av geografiska områden för säker fart för respektive fartygsklass, dvs fartområden. Den nya regeln baseras på ett EU-direktiv för civila passagerarfartyg. Här beskriven utredning undersöker säkerhetseffekten av denna regel i förhållande till säkerhetsnivån i marinens verksamhet 1990–2015. Utredningen följer the International Maritime Organization (IMO:s) process för en Formal Safety Assessment (FSA). Risken i marinens verksamhet under perioden har inte varit försumbar, men analysen visar också att regeln som definierar fartygens fartområden inte leder till säkerhetshöjningar som står i proportion till dess operativa kostnad. Identifierade lärdomar innebär att en FSA kan visa om en regel påverkar säkerhetsnivån som tänkt och hur den i övrigt påverkar verksamheten. Speciellt belyses behovet av att kunna analysera föreslagna bestämmelser i termer av säkerhetseffekt, men också i termer av lämplighet i förhållande verksamheten i stort.

TODAY, THE SAFETY work on military vessels is influenced by civilian approaches, regulations and codes. This influence introduces important civilian lessons into naval vessel design, but can also potentially be in conflict with military task solving.<sup>1</sup> One regulation, which is largely influenced by IMO codes, is the Swedish Military Ship Code<sup>2</sup> formulated by the Military Safety Inspectorate. Risk management could present an approach for investigating if the civilian influence on the code leads to decisions and solutions that hinder military task solving. IMO's Formal Safety Assessment (FSA) is an approach for such an investigation. The FSA process developed by the IMO is a risk analysis and cost-benefit assessment methodology.<sup>3</sup> This methodology corresponds to the Swedish Armed Forces risk management ambition, which states that "managers are recommended ... to reason in cost-benefit terms .... If not, it is possible that the minimization of

identified risks is getting a too large focus which will hinder the task solving".<sup>4</sup>

The effect of using IMO and classification society-based codes for the design of naval vessels has been found to assist in the engineering process and to guarantee a basic level of safety.<sup>5</sup> However, the approach is not sufficient for guaranteeing survivability and thus safety in military cases.

In 2010, the Swedish Navy introduced a new rule re-defining the sea area of safe operation for respective classes of vessels.<sup>6</sup> The new rule is based on a civilian EU directive developed for European passenger vessels.<sup>7</sup> The Swedish Military Ship Code is not intended to limit military (wartime) operations. However, a Swedish naval vessel does always operate under a basic readiness level and therefore under military conditions.<sup>8</sup> Hence, there is a potential conflict between the rules that prescribe aspects of vessel use (i.e. limits use), and military task solving.

This potential conflict and the principle of using civilian (IMO-based) rules for areas such as operations have not, so far, been investigated. Therefore, the case, the regulation on sea areas of safe operation, was chosen because it represents a suitable type of regulations because:

- the suitability of changes made in 2010 has been discussed within the Swedish Navy;
- the regulation regulates operations, not technology;
- the rationality behind the regulation changes as well as the regulation itself are documented; and
- the safety effects of the regulation have so far not been investigated.

The objective of this paper is to describe an investigation performed and to focus on the meta lessons identified by applying the FSA structure to a military maritime safety case. The investigation analyses the safety level in the Swedish navy as a result of the regulation on sea areas of safe operation. The objective of the described investigation was to investigate the safety impact of the new sea areas given the Swedish Navy's concept of operation, staffing structure, and competence. An additional objective was to determine if the rule is cost effective, and whether, if needed, sufficiently low risk can be achieved by an alternative sea areas definition, which has less impact on the Navy's operations.

## Method and Material

### A Risk-Based Perspective

Risk-based approaches are well established in maritime safety. The first risk-based regulation was the damage stability rules in IMO's Safety of Life at Sea regulation (SOLAS74),

which assessed the probabilistic damage stability. In 1997, the IMO adopted the Formal Safety Assessment as a risk-based approach to rule making.<sup>9</sup>

The Swedish Armed Forces, similar to other military forces, uses risk-based approaches in decision-making. Typically, military risk-based approaches do not differ substantially from civilian applications of risk management.<sup>10</sup> The Swedish Armed Forces' common risk-management model manual states that "tasks are to be solved and the effects achieved despite the risks, but in a considered manner".<sup>11</sup> The manual also quotes the NATO's Allied Command Operations Force Protection Directive 80, which states that the organization should "accept risk if benefits outweigh potential losses. Protecting the force and meeting the mission are both necessary to be successful".<sup>12</sup> Thus, the focus for the Swedish Armed Forces, NATO and the IMO regulations is to weigh benefits against risks and to maintain risk within tolerable levels.

In this study, risk is quantified in accordance with the IMO recommendations,<sup>13</sup> which is also clarified as a result of the project SAFEDOR.<sup>14</sup> This approach has many similarities in terms of how safety is described and analysed in the other traffic modes, both nationally and internationally.<sup>15</sup>

The FSA quantitative risk perspective used by the IMO, with a focus on the number of fatalities (and injured), means that maritime safety is managed in a more inclusive manner compared to the pure technical traditional prescriptive analyses in regulatory regimes.<sup>16</sup> FSA focuses on the consequences for the crew and passengers and, thereafter, on the effects of organizational factors and working practices. The approach thus provides information about the overall level of risk and includes both the technical status of the vessel and how the vessel is operated

including organizational, technical and human related factors.<sup>17</sup> Any quantitative risk approach "should be used in ways that match its strengths – the focus of analysis should be on finding ways to manage risk", the approaches "should not be used in ways that place excessive reliance on its accuracy".<sup>18</sup> This is also true for the FSA. Therefore, the conclusions drawn and lessons identified here must focus on the general findings of the assessment, not on the quantitative risk as a result of the risk analysis. It must also be acknowledged that FSA, as all models, will analyse a simplification of the case studied and that there are socio-technical aspects of risk<sup>19</sup> that will not be captured by the FSA approach.

## The IMO Formal Safety Assessment

FSA is a risk analysis and cost-benefit assessment approach for "the evaluation of new regulations for maritime safety... or in making a comparison between existing and possibly improved regulations".<sup>20</sup> FSA is "consistent with the current IMO decision-making process" and gives decision makers the possibility to "appreciate the effect of proposed regulatory changes in terms of benefits (e.g. expected reduction of lives lost...) and related costs ... affected by the decision".<sup>21</sup> Thus, in this study, FSA is considered a suitable approach for evaluating the regulation prescribing the sea areas of safe operation for the vessels of the Swedish Navy.

Several studies have been performed on the application of the FSA.<sup>22</sup> The studies highlight the diversity of applications for the FSA within the maritime industry and the diversity of key issues that must be included in the assessment depending on the focus of the study. Kontovas and Psaraftis identify that "FSA is a tool that is only as

good as the way it is being used" and that it must be understood that the FSA process is designed to produce decision support, not final answers.<sup>23</sup> The studies also identify that FSA needs further development as well as application to more cases to learn more about the limitations and benefits. Some of the proposed changes were included in the revised FSA guideline in 2013.<sup>24</sup>

An FSA consists of the following five steps: (1) identification of hazards; (2) risk analysis; (3) risk control options; (4) cost-benefit assessment; and (5) recommendations for decision-making.<sup>25</sup> This structure was used in the investigation described here, and steps (1) to (4) represent the structure of Section 3. Based on the findings in the first four steps, Section 4 discusses the recommendations and lessons identified from the application of FSA.

According to the IMO, an FSA is based on three different perspectives:<sup>26</sup>

- Objective analysis of the appropriate incident statistics, where reliability, uncertainties and validity are assessed.
- A proactive analysis of possible scenarios, i.e., analysis of the probabilities of a breakdown based on information on the sub-systems incidents.
- Expert assessments, both to support the proactive approach and to increase the quality of the existing data.

The three perspectives described above are not unique to the IMO; in Sweden, equivalent perspectives are found in the Swedish Civil Contingencies Agency's (MSB) guidance for risk and vulnerability assessments.<sup>27</sup>

Often in the IMO approaches, the level of harm is narrowed to the loss of life; therefore, risk is an expression of the frequency and number of fatalities, i.e., life safety is deemed to refer to the risk of the loss of life and is

usually expressed as fatalities per year. An equivalent fatality concept is recommended by the IMO to address not only fatalities but also disabilities and injuries. According to the FSA, risk should at least be judged from two perspectives: individual risk and societal risk.<sup>28</sup>

Individual risk is used when the risk from an accident is to be estimated for a particular individual at a given location. Societal risk is used to estimate the risks of accidents affecting many persons, e.g., catastrophes. Societal risk includes the risk to every person, although a person is only exposed on one brief occasion to that risk. In this study, societal risk is expressed as a Frequency Number diagram (FN diagram). FN-diagrams show the relationship between the cumulative frequency of an accident and the number of fatalities ( $N$ ) in a multidimensional diagram, where FN is given by

$$FN(N) = \sum_{i=N}^{N_{max}} fr_N(i) \quad \text{Equation 1}$$

and  $fr_N$  is the frequency per ship year of exactly  $N$  fatalities.<sup>29</sup>

An equivalence fatality concept aims at being able to compare and combine the statistics on fatalities and injuries. This is used because measures that will reduce the occurrence of fatalities also tend to reduce injuries proportionally.<sup>30</sup> Therefore, an equivalence ratio between fatalities and injuries must be known or assumed. The equivalence ratio between the number of fatalities, number of injuries and number of incidents depends on the reporting regimes, the reporting culture and on how injuries and incidents are defined in the organization under study. In this study, there is no difference made between severe injury and minor injuries. Therefore, based on the equivalence ratios proposed by IMO<sup>31</sup> and compilation of several international surveys described by the Swedish

Civil Contingencies Agency,<sup>32</sup> the equivalence ratio here is set to 1:20:100. However, there is uncertainty in the figures describing the number of injuries and incidents; consequently, larger uncertainties occur when the figures are translated into an equivalent number of fatalities. Therefore, the uncertainty is particularly high for the composite decision parameters.

IMO proposes decision parameters based on individual risk; societal risk in terms of FN diagrams; costs of each risk control option; the Implied Costs of Averting a statistical Fatality (ICAF); and the cost of reducing the risk of injuries and ill health.<sup>33</sup> The risks for passengers and for third parties are to be used if relevant and appropriate.<sup>34</sup> In this study, all persons on board are treated as crew, and the risk level for third parties is below measurable levels. Therefore, the risk for passenger and for third parties is not relevant or appropriate to include.

In the document, *Decision parameters including risk acceptance criteria*, the IMO proposes criteria for individual and societal risk.<sup>35</sup> The proposed individual risk criteria are based on criteria published by the UK Health & Safety Executive and define that the maximum tolerable risk for existing ships for crewmembers is  $10^{-3}$  annually and negligible risk is below  $10^{-6}$  annually. The IMO states that risks below the tolerable risk but above the negligible level should be made as low as reasonably practicable (ALARP) by adopting cost-effective risk reduction measures.

The societal risk criteria depends on the estimated economic importance of the activity under study.<sup>36</sup> The average acceptable frequency of accidents involving one or more fatalities ( $F_1$ ) is given by

$$F_1 = PLL_A / \sum_{N=1}^{N_u} 1/N. \quad \text{Equation 2}$$

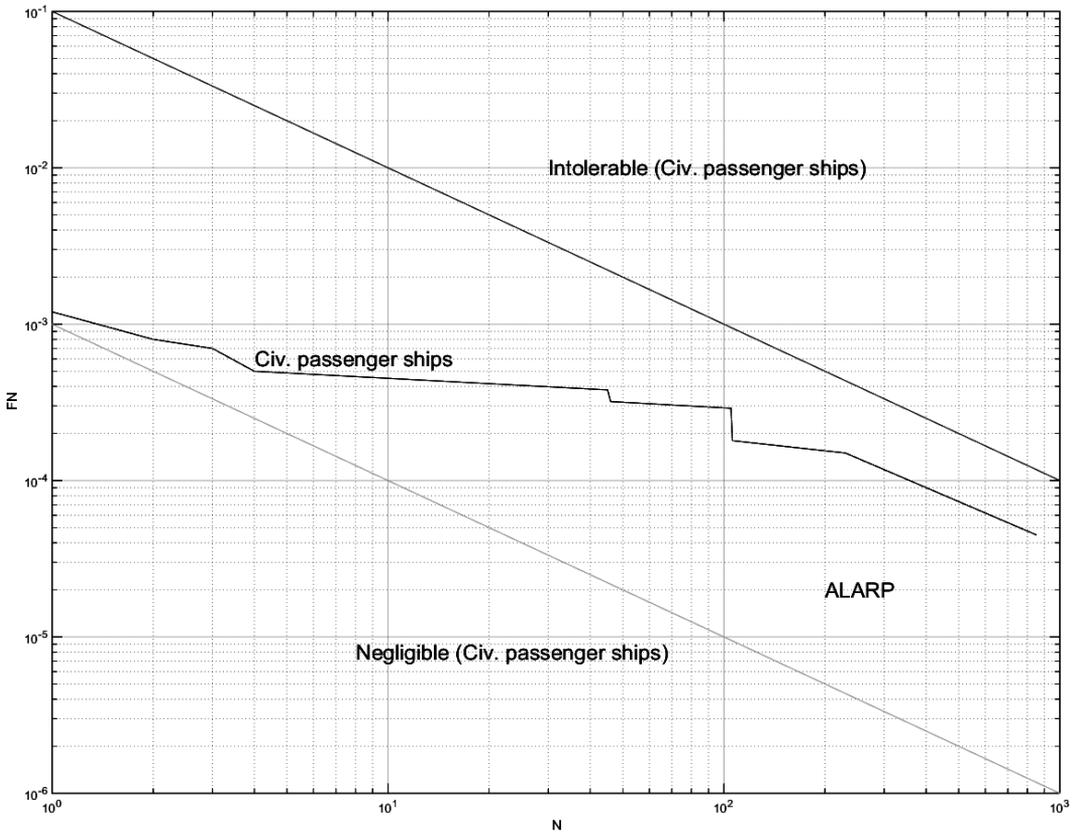


Figure 1. FN-diagram showing the societal risk per ship year in relation to the number of fatalities for passenger ships worldwide for the years 1989–1998. Data and limits according to IMO.<sup>41</sup>

In Equation 2,  $N_u$  is the upper limit of the number of fatalities in one incident (crew size).  $PLL_A$  is the average acceptable potential loss of life and given by

$$PLL_A = r \cdot EV \quad \text{Equation 3}$$

where  $r$  is the average fatality per value unit, and  $EV$  is the economic value of activity per ship.<sup>38</sup> The ALARP region for the FN-diagram is then given by assuming that the risk is intolerable if it is more than one order of magnitude over  $F_1$  and negligible if it is more than one order of magnitude below  $F_1$ .<sup>39</sup> Based on US and Norwegian studies,  $r$  for crews is estimated to be approximately

one fatality per billion USD, and  $r$  for passengers is estimated to be approximately six fatalities per billion USD.<sup>40</sup> Figure 1 shows the resulting limits for negligible and intolerable societal risks for international passenger ships together with the passenger ship statistics for the 1989–1998 period.

The IMO measures the operational cost in economic terms (normally USD),<sup>42</sup> which is a natural measure when commercial activities are studied. For military operations, other assessments must be made (and metrics formulated) to assess how large the negative effects are. Limiting the operational area of a vessel leads to an operational impact (cost)

on many tasks that must be performed by the Navy, and the impact of the limits introduced will vary with the task. Therefore, this work only provides a general discussion of the operational cost of introducing restrictions (limiting the sea area of operation) based on two main aspects:

- the rules limit the areas where the vessel may operate and thus affect the Navy's capability in relation to presence at sea, and
- rules that affect the individual vessel operation in geographic terms will reduce the current alternatives when operating close to the limiting line. This leads to effects on exercises as well as the capability achieved by exercises because "you should train the way you want to fight".<sup>43</sup>

## Material

The Swedish Military Ship Code is published and developed by The Swedish Armed Forces' Military Safety Inspectorate.<sup>44</sup> The inspectorate's tasks are conducted under a directive from the Swedish Supreme Commander. The directive states that the inspectorate shall "examine and inspect, and where needed, supervise the Armed Forces military land and maritime operations with regard to military land and maritime safety".<sup>45</sup>

The Swedish Military Ship Code (in Swedish abbreviated RMS) is a compilation of the rules that regulate military maritime safety.<sup>46</sup> The code is not aimed, or intended, to regulate how military tasks are to be solved or contribute to tactics.<sup>47</sup> The code covers areas such as safety management (Chapter RMS-S), training, certification and watch-keeping (Chapter RMS-P), operation (Chapter RMS-D, which mainly include the sea area of operation and dangerous goods),

and ship design (Chapter RMS-F). The areas are regulated based on the civilian regulations and codes for the respective areas.<sup>48</sup> The chapter for ship design is based on the NATO Naval Ship Code (NSC), which, in turn, is based on and benchmarked against IMO conventions and resolutions.<sup>49</sup> The code does not include measures specifically designed to address the effects of military attack.<sup>50</sup> The effect of using an IMO and classification society-based code such as the NSC for the design of naval vessels has been found to assist in the engineering process and to guarantee a basic level of safety; however, it is not sufficient for guaranteeing survivability and thus safety in military cases.<sup>51</sup> The effects of using civilian (IMO-based) rules for areas such as operations (as done in Chapter RMS-D) have not been investigated so far.

In 1998, the European Commission issued a directive "on safety rules and standards for passenger ships".<sup>52</sup> The purpose of the directive was to "introduce a uniform level of safety of life and property on new and existing passenger ships and high speed passenger craft ... on domestic voyages".<sup>53</sup> The directive states that the Commission is "seriously concerned" about accidents involving passenger ships. The directive also states that it is necessary to remove trade barriers and establish harmonized safety standards where "the main reference framework for the safety standards should be the 1974 Safety of Life at Sea Convention".<sup>54</sup> The directive states that "ships should be divided into different classes depending upon the range and conditions of the sea areas in which they operate". According to the directive, ships are divided into the following classes:<sup>55</sup>

Class A: "voyages other than voyages covered by Classes B, C and D".

Class B: "at no time more than 20 miles from the line of coast".

Class C: "in sea areas where the probability of exceeding 2.5 m significant wave height is smaller than 10 % over a one-year period ... or over a specific restricted period of the year for operation exclusively in such period", "at no time more than 15 miles from a place of refuge" and at no time "more than 5 miles from the line of coast".

Class D: "in sea areas where the probability of exceeding 1.5 m significant wave height is smaller than 10 % over a one-year period ... or over a specific restricted period of the year for operation exclusively in such period", "at no time more than 6 miles from a place of refuge" and at no time "more than 3 miles from the line of coast".

As shown above, none of the definitions enable the crew to make decisions based on the current conditions and forecasts for the period of interest. Subsequently, according to the directive, a sea area is deemed suitable and safe or unsuitable and unsafe based on yearly averages; this creates consistent repeatable conditions for commercial ships on repeated journeys. However, such deterministic formulations have also generally been shown to devolve on-board responsibility and inhibit innovation, i.e., to create a poor safety culture, which can increase the possibility of accidents.<sup>56</sup>

In Sweden, the directive text was implemented for all types of civilian ships and then in 2010 as a part of the Swedish Military Ship Code as Chapter 2 of the section on operations (RMS-D).<sup>57</sup> The changes were recommended by the Swedish Accident Investigation Authority in a report on an accident with a combat boat in 2006.<sup>58</sup> However, an analysis of the report shows that the recommendation was not a result of any documented analysis of how a new sea area rule would affect safety in general or in relation to the specific accident investigated. Since the implementation, there have been

a couple of changes to clarify the rule and exemptions introduced for specific vessels and vessel types. Figure 2 illustrates some of the resulting limiting lines for smaller naval vessels.

Prior to 2010, the permitted areas of operation were largely based on the sea state expected for the duration of the operation in relation to the vessel's speed and ability to transport the vessel and crew to safety.

The material used for the identification of hazards, the risk analysis and the proactive analysis is collected from the following:

- Official accident reports for nine of the ten most severe accidents for the studied period.<sup>60</sup>
- Summary of the Swedish Armed Forces operation statistics on incident types for the years 2007–2015 from the Armed Forces accident reporting system (DIUS).
- Summary of the Swedish Armed Forces accident statistics on injuries and injury types for 2010 from the Armed Forces accident reporting system (DIUS).
- Official operational statistics (hours of operation per vessel type) and list of operational vessels (the amphibious battalion excluded) for the years 2001–2014.<sup>61</sup>
- Summary of the Swedish Armed Forces operational statistics (hours of operation per vessel type) and list of operational vessels for the amphibious battalion for the years 2001–2015.
- Qualitative descriptions on how the operational profiles have changed over the studied period.

The different sources are, to an extent, overlapping and show no contradictions. The material is judged to provide a fair representation

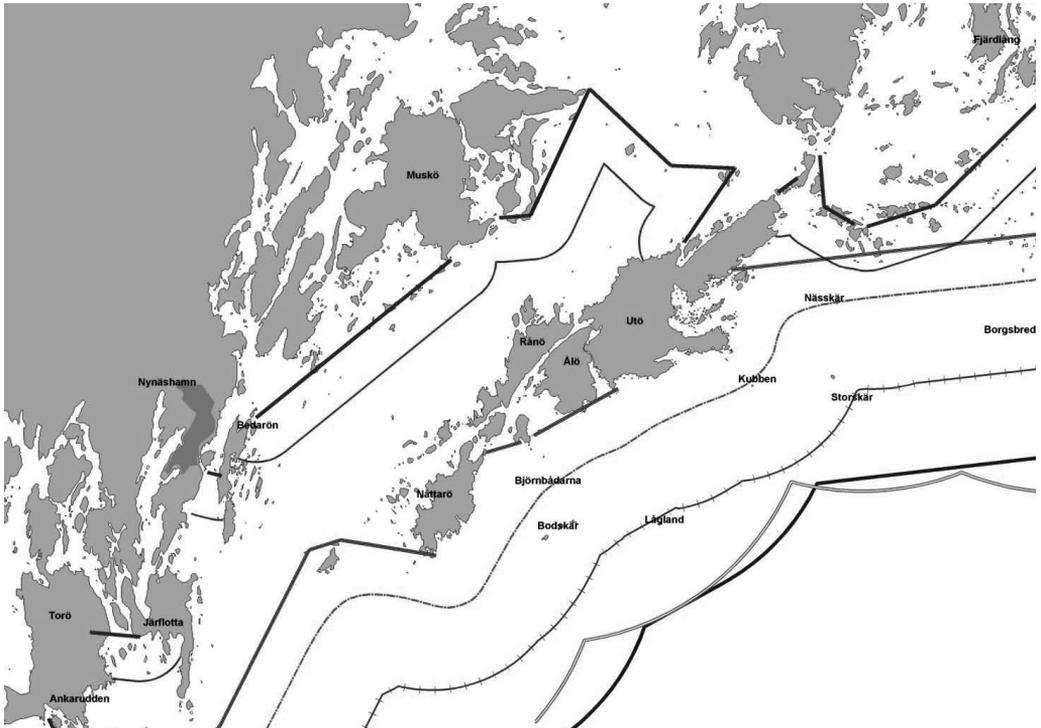


Figure 2. Sea area limits in the southern part of the Stockholm archipelago. The lines shown are the results of the summer and winter sea area of operation limitations for different types of vessels.<sup>59</sup> From the shore and outwards, the limits are denoted E, E+1 nm, D, D+1 nm, D+3 nm, C (blue solid) and 6 nm from a safe harbour (light green solid). Copyright: Håkan Persson and Peter Hammarberg, the Swedish Armed Forces, 2016.

of the operations and incidents. However, over the studied period, there have been changes in the reporting objective, the culture and the systems.

Because of the varying incident report quality over the period, the data sources are chosen to obtain the best available data. For example, 2010 was chosen for an in-depth study on injuries, injury types and number of incidents in relation to operational hours. This selection occurred because 2010 represents a year with a high number of reported incidents due to a well-functioning reporting system throughout the organization. Using statistics from 2010 was a more conserva-

tive approach than using the actual statistics for each year.

### Complementing Methodical Support and Contextual Knowledge

In order to reach sufficient validity in the performed investigation the FSA approach was complemented with more specific uncertainty theory, treatment and propagation as described by Paté-Cornell et al., Abrahamsson and Liwång.<sup>62</sup> The assessment was also put to a peer review in order to ensure that the important aspects of naval operations were characterized correctly.

## Risk Assessment

### Identification of Hazards

The purpose of the investigation was to investigate the level of risk in the Navy's operations in general and particularly to deepen the understanding of how the rules regarding the sea area of safe operation affect the level of risk. Therefore, the incident statistics were analysed from multiple perspectives.

First, major hazards were identified qualitatively by examining the nine reports describing the major accidents during the period.

Second, the relation between incidents, injuries and operation hours were analysed in detail for 2010. This analysis was performed to estimate the number of injured in the incidents that are not addressed in reports such as accident investigations and to estimate the number of incidents per year with no injuries or fatalities. The result was also compared to the incidents for the years 2007–2015, which confirmed that 2010 was a representative year in terms of the incident types, but with approximately 70 percent more incidents reported. Given the operational profile of the studied years and that there is no particular difference between the years in operational terms; it is here assumed that the increase in incidents and the sub-

sequent increase in injuries are a result of a decrease in underreporting during 2010.

Third, hazards that can lead to severe consequences if the vessel is far from shore, i.e., that could be risk-drivers if the sea areas are extended, were quantitatively examined for the years 2007–2015. The hazards selected in the analysis were fire, blackout, collision, and vessels lost. The four hazards represent relatively wide types of incidents that all potentially could have far-reaching effects on the vessel and its personnel. Therefore, the hazards could lead to more severe consequences if they are combined with more unlimited vessel movements (rules with less constricted sea areas).

Table 1 describes the resulting incident and operational data.

The uncertainty in terms of the number of injured and the number of incidents include that the actual number could be as much as 50 percent and 100 percent higher, respectively.

The uncertainty in terms of the estimated operational fleet at risk, in ship years, reported in Table 1 is a result of the fact that hours of operation per year for naval vessels is lower than that for typical civilian vessels. Within the IMO guidelines, there is no description of how, and if, the calculation of ship-years should consider the actual operational hours per year. The lower figure in the range represents the equivalent number of

The number of fatalities	4 (divided on 3 incidents)
Estimated number of injured*	150-215 (up to 8 people per incident)
Estimated number of incidents	600-1200
Estimated fire, blackout, collision or vessel lost	55-110
Relation between fatalities: injured: incidents	1: 38-54: 150-300
Estimated number of person at risk [person-years]	13 000 (i.e. 500 person-years per year)
Estimated operational fleet at risk [shipyears]	280, 2 700 or 4 800 (i.e. 11, 100 or 180 shipyears per year)

\* ) All injuries onboard needing at least medical attention (such as a dislocated shoulder, man over board or a concussion, but not a mildly bruised thigh). Includes 5-7.5 injuries per year estimated from 2010. Approximately 2/3 of all injuries are a result of work/maintenance performed onboard and slipping/falling onboard.

Table 1. Summary, incident and operational data, the Swedish Navy from 1990 to 2015.

vessels based on the number of operational hours reported; the middle figure is a conservative estimate of the actual number of vessels operated, and the upper figure is based on a conservative estimation of the number of vessels in the organization.

## Risk Analysis

The total number of reported incidents is low, particularly in relation to the number of injured. This finding could mean that the reporting culture in the Navy is high if the incident results in some type of injury but that the incidents without injury are not reported to the same degree. The figure could also be the result of pure technological incidents being few, owing to a high material standard.

Table 2 describes the main cause of the ten most severe incidents where the underlying causes are studied. In the analysis of the

cause of these incidents it can be concluded that the three most serious incidents (leading to, in total, four fatalities) were initiated by activities called for by the military task and are thus the result of situations that lie outside the basis for the civil regulations.

Four of the incidents described in Table 2 are related to sea state and wave height (boat #848 lost and the green water incidents with #451, #831 and Malmö). From these incidents, it can be identified that it is the decisions taken on board in relation to the sea state, and not the geographical area, that led to incidents. It is also important to note that in seven of the ten studied accidents, it is found that the proximity to land is a risk driver that increased the probability of the incident.

Table 3 displays the resulting individual risk. In accordance with the IMO recommendations,<sup>64</sup> each risk is presented individually

Incident, vessel designation(s), year	Consequence		Main cause
	Personnel	Vessel	
Collision, #867 and #929, 2004	2 fatalities	Damage	The organization did not consider the risk factors that were introduced by the military task
Collision, Nynäshamn and Luleå, 1991	1 fatality	Severe damage	The organization did not consider the risk factors that were introduced by the military task
Shooting Accident, Utö, 2008	1 fatality	-	The organization did not consider the risk factors that were introduced by the military task
Loss of watertight integrity, #848, 2006	8 injured	Lost	The organization did not consider the relevant risk factors (in relation to technical problems)
Collision with structure, #820, 1999	7 injured	Severe damage	The organization did not consider the relevant risk factors (possible in relation to technical problems)
Collision with buoy, #091, 2014	4 injured	Severe damage	The organization did not consider the relevant risk factors
Green water incident, #451, 1992	1 injured	Damage	No report available, most probably not a result of the military task
Grounding, #881, 2003	-	Damage	The organization did not consider the relevant risk factors
Green water incident, #831, 2009	-	Damage	The organization did not consider the relevant risk factors
Green water incident, Malmö, 2008	-	Damage	The organization did not consider the relevant risk factors

Table 2. Cause of incident. Based on analysis of each accident from the analysed reports;<sup>63</sup> for the accident with Amphibious Command Boat #451, no report has been found.

Decision parameter	Risk in relation to maximum tolerable risk for crewmembers
All fatalities	0.3
Fatalities as a result of military tasks	0.3
Other fatalities	-
All injured*	0.6 - 0.8
Injured as a result of military tasks*	0.1 - 0.2
Other injured*	0.5 - 0.7
Combined**	0.4 - 0.5
Combined**, as a result of military tasks	0.2 - 0.2
Combined**, other cases	0.2 - 0.3

\*) As a result of the equivalence ratio used, the criteria is set to 20 times the IMO criteria for fatalities.

\*\*) (Number of fatalities)+(number of injured)/20. The criteria is set to two times the IMO criteria for fatalities.

Table 3. Individual risk (per person-year) in the Navy from 1990 to 2014. Fatalities, injuries, and combined based on a composite parameter with an equivalence ratio between fatalities and injuries of 1:20. Criteria according to IMO for existing ships as described in the section The IMO Formal Safety Assessment.

(fatalities and injuries) and complemented with a combined parameter.

By using Equation 2 and 3,  $r$  for crews,  $EV$  based on the operational cost of the Swedish Navy for 2014<sup>65</sup> and  $N_{it}$  set to 15, the ALARP region for the Swedish Navy’s activity can be calculated. The resulting ALARP region is dependent on the estimated size of the fleet at risk. If the fleet is estimated to be 100 vessels per year (i.e., 2600 ship years over the 26 years studied), the limits for the Swedish

Navy are 0.2 times the limits for passenger vessels worldwide shown in Figure 1.

In Figure 3, the FN-diagram shows the societal risk per ship year in relation to the number of fatalities in the Swedish Navy during the period 1990–2015. The uncertainty displayed in relation to the risk criteria (ALARP limits) for civilian passenger vessels is a result of how to measure the fleet at risk (ship years produced) during the period. Here, 2 600 ship years is assumed to be the

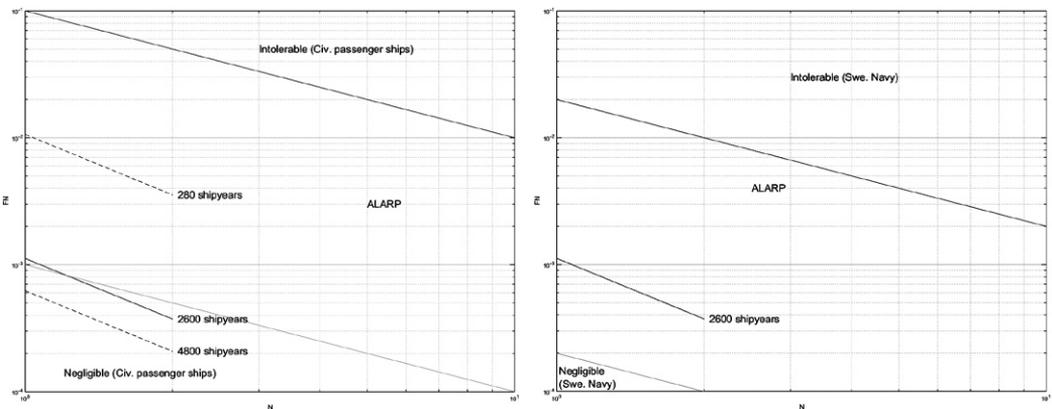


Figure 3. FN-diagrams for societal risk per ship year in the Swedish Navy during the 1990–2015 period. To the left, risk levels and uncertainty in relation to criteria for civilian ships according to the IMO.66 To the right, risk level in relation to criteria specifically developed for the Swedish Navy.

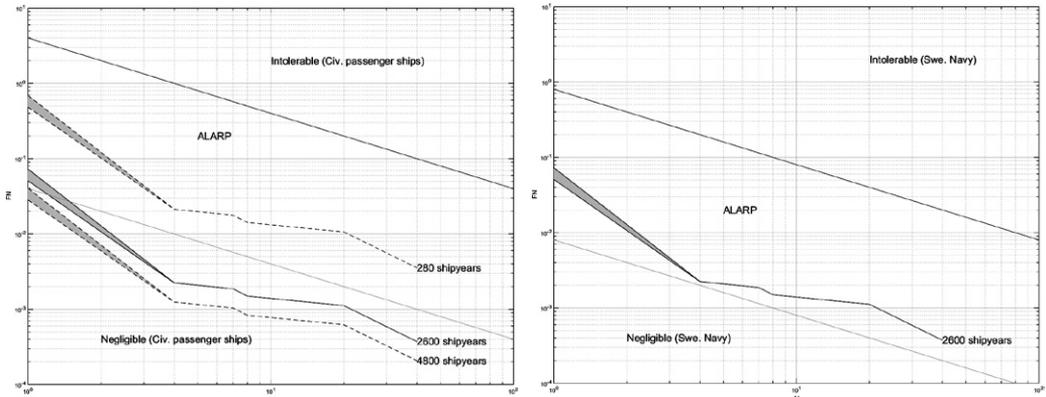


Figure 4. FN-diagrams for societal risk per ship year for a composite measure combining fatalities and injuries in the Swedish Navy during the 1990–2015 period. The equivalence ratio between fatalities and injuries 1:20. To the left, risk levels and uncertainty in relation to criteria for civilian ships. To the right, risk level in relation to criteria specifically developed for the Swedish Navy. Because of the equivalence ratio used, the limits for intolerable and negligible are set to  $2 \times 20$  times the limits used in Figure 3.

most realistic estimation. If the ALARP region specifically developed for the Swedish Navy above is used, the risk level is in the ALARP region independent of the estimated fleet size. The uncertainty introduced by the size of the fleet at risk is removed, as both the risk level and the risk criteria for the societal risk are dependent on the size of the fleet at risk.

The FN-diagram in Figure 4 shows societal risk per ship year for a composite measure combining fatalities and injuries in the Swedish Navy during the period 1990–2015. In Figure 3, the uncertainty displayed is a result of how to measure the fleet at risk during the period; however, there could be underreporting of less severe injuries (see Table 1). Here, 2 600 ship years is assumed to be the most realistic estimation.

Both individual risk and societal risk are most probable in the ALARP region. The highest risk contribution to both types of risk measures is the contribution from everyday accidents on-board in relation to the

vessel as a workplace independent of vessel operations, i.e., from *other injured* in Table 3 and  $N = 1$  in Figure 4.

## Risk Control Options

The risk control options under study are the rules limiting the sea area of safe operation. The risk analysis has shown that the link between the sea area of operation and safety is weak. This section's proactive analysis investigates the potential risk increase, in relation to the risk levels identified, as a result of a less restrictive rule. Such a rule could result in accidents that would lead to more severe consequences if the distance to shore or assistance is greater at the time of an incident. It is here assumed that as much as 50 percent of the incident types (fires on board, blackouts, collisions and vessels lost (estimated as a total of 55–110 incidents, see Table 1)) in the worst case, could occur far from assistance if the sea areas of safe operations were extended.

This would then mean that approximately one to two incidents per year could lead to severer consequences if the vessel was further from shore or other types of assistance. A worst-case analysis of such incidents identify that the incidents could lead to an increase of the individual risk and the societal risk. However, the analysis also shows that the increase of the risk (for all types of risks here studied) is only 1 to 2 percent, i.e., the risk increase is estimated to be negligible.

That the proximity to land is identified as a risk driver in several incidents is not included in the proactive analysis.

### Cost-benefit Assessment

Based on the understanding of operational cost as it is described above, it can be identified that the operational effect of limiting the sea areas of safe operations is that the available number of vessels is reduced for tasks that must be solved away from the coast, that the vessels are more predictably close to the limiting line and that the crews cannot train as needed. The operational cost is therefore not negligible in task solving and in training and exercises. On a qualitative five step effect/cost scale ranging from (1) insignificant to (5) extreme, the study finds the operational cost of reducing the sea areas of safe operation to be (2) minor or (3) moderate estimated to reduce the effectiveness of the navy by at least a couple of percent; however, the effect is task dependent.

Given low risk levels in general, the estimated safety increases negligibly because of the sea area of operation rule and the possible negative safety effects of the rule; the minor to moderate cost increase is not proportional to the estimated safety effects. Given the result of the proactive analysis, the estimated cost for saving one life (ICAF) with the existing sea area of operation rule

is 90 million USD per life if the operational cost is one percent and 270 million USD per life if the cost is three percent.<sup>67</sup> This ICAF is at least ten times higher than the ICAF deemed cost effective in IMO's decision-making.<sup>68</sup>

Therefore, despite the uncertainties in this analysis and the limited material, the examined approach for limiting the sea areas of safe operations for the Swedish Navy is not assessed to be cost effective.

### Validation of the Assessment

Rae et al. offers an extensive approach for self-validation of quantitative risk analysis with the ambition to make the assessment repeatable, valid and accurate and Goerlandt et al. discusses the validity of quantitative risk analysis in general terms.<sup>69</sup> The two frameworks were used to validate the performed investigation. The validation showed that the IMO documentation explicitly assists in avoiding maturity level one and two flaws described by Rae et al.<sup>70</sup> However, in order to reach higher maturity levels the IMO documentation needed to be complemented with more explicit methodical support in relation to uncertainty treatment, propagation and reporting and with context specific peer review. Based on the validation the performed assessment is deemed accurate enough in relation to the goal at hand but a more extensive scientific knowledge on risk in the specific context is needed to reach above maturity level four.

### Results, Recommendations and Meta Lessons Identified

In the period studied, there have been safety issues leading to risks higher than negligible. For the studied severe accidents, the identified risk levels are a result of decisions made

on-board when solving military peacetime tasks. However, the quantitative analysis of the nine severe accidents shows that not only human factors affect the probability of an incident. The military education, training, organization and personal safety equipment also result in relatively low levels of consequences in severe incidents that involve high speeds, cold water and vessels lost or severely damaged. These incidents would typically lead to multiple fatalities for a civilian vessel.

The less severe incidents leading to injuries were most often a result of maintenance work performed on-board independent of the vessel operation. Therefore, in the material, there is a low number (<1) of accidents per year related to the vessel operation with potentially severe consequences and a higher number (>5) of accidents per year related to work on-board leading to minor injuries.

Safety trends could possibly be investigated by dividing the fatalities and the severe injuries (according to Table 2) into five five-year periods. The number of fatalities then shows a minute decrease, and the number of severe injuries shows a minute increase over the period. However, the changes are not significant, and the material therefore indicates no substantial changes in the safety level over the studied period.

## Recommendations for Decision-making

The investigation recommended the Swedish Armed Forces to:

- continue to develop and strengthening the methods and knowledge of risk analysis on-board to support operational decisions on-board and reduce unnecessary risk taking,

- change the sea area rule so that the limitations rest on operational considerations specifically for each mission (i.e., defining allowable sea states and distance to assistance rather than allowable geographical areas), and
- ensure that there are processes and competence that continuously analyse safety at sea in general and in relation to new proposed rules and changes in existing rules in particular.

## Meta Lessons Identified

An investigation in accordance with the FSA, as performed here, in qualitative terms analyses both the effectiveness and the effects of the rule. This finding means that an analysis can show if a regulation affects safety in the manner intended and if there are other means by which the regulation affects the operations. However, in order to reach high validity the FSA approach needed to be supported by more explicit support on uncertainty treatment and propagation and by a peer review with strong contextual knowledge. The quantitative risk estimated was not, and should not, be in focus.

The investigation particularly highlights the need for an approach for analysing proposed safety changes both in terms of effectiveness and in terms of suitability. In 2008, after the accident in which Combat boat #848 was lost, the Swedish Accident Investigation Authority recommended 11 changes.<sup>71</sup> One of those changes was to implement new sea areas of safe operation according to the civilian regulation; in addition, there were several regarding strengthening the crews' risk understanding.<sup>72</sup> In this investigation, the recommendation to implement new sea area limitations is shown to be problematic in several ways:

- the proposed changes would not have affected the accident with Combat boat #848,
- the proposed rule to implement was neither understood nor analysed by the Swedish Accident Investigation Authority, and
- the proposed changes most likely affect safety culture negatively, as their prescriptive nature of safe and unsafe sea areas contradicts the general need to develop the crews' risk understanding.

From this example, it can be identified that the effectiveness of the proposed changes must be analysed by the Accident Investigation Authority or by the Armed Forces. The result of an accident investigation is a set of recommendations; however, these recommendations must be analysed before they lead to new rules, particularly if the recommendations affect operation types that the Accident Investigation Authority have limited insight into. It must be ensured that new rules have the intended effect on safety; this responsibility must be taken by the organization deciding the new rules.

This investigation has shown that the recommendations to change the sea area rule led to a rule that has very limited positive effects, possible far-reaching negative effects and substantial operational costs.

The safety level for a vessel is a complicated relationship between several factors including the vessel type, the quality of the vessel's maintenance and the vessel operation (seamanship).<sup>73</sup> This finding is also identified in this investigation. It is stated in earlier studies using the FSA approach that "human error problems" can and must be included.<sup>74</sup> However, this study shows that human factor strengths also can and must be included, as they had an important

impact on the link from incident to consequence and are an important part of the seamanship. The study identified that the high level of safety training of the persons on-board independent of their role resulted in relatively limited or minor injuries despite severe incidents.

An approach in accordance with the FSA structure is suitable even for areas outside the IMO's typical scope. The FSA structure does not limit the approach to operational conditions as defined by civilian ships. However, the analysis needs to incorporate operational knowledge suitable for the area under study.

The view on safety has changed over the period; therefore, how safety and incidents are understood and reported has also changed. In addition, the view and role of the Swedish Armed Forces have changed several times over the period, and these changes have affected how safety is to be understood. Therefore, the reliability of an FSA largely depends on reliable data, particularly operational data.<sup>75</sup> In this study, this was highlighted by the challenges introduced by the varying quality of the reported number of injuries and the substantial uncertainties in how to establish a representative size of the fleet at risk.

In relation to naval vessel risks, it is important to remember that the incidents and accidents studied here are a result of peacetime operations, i.e., during training and exercises or during circumstances similar to civilian vessel operations. In other situations, the effect of rules could be more far-reaching.

In studies where the technical aspects of the safety and survivability for naval vessels is studied, such as watertight subdivision for damage stability,<sup>76</sup> plate thickness redundancy and separation of critical systems,<sup>77</sup> it is often found that the civilian-based rules do not contradict military safety needs. In those

cases, civilian regulations and rules could be shown to represent a minimum requirement; in addition, safety and survivability can be added by enforcing stricter regimes. This study identifies that the concept of civilian rules as a suitable minimum level is not necessarily true for rules that regulate operations. Concerning operations, the concept of operations for military vessels differ such that civilian rules can become irrelevant.

In general, the case has also shown that the proactive perspective of an FSA investigation of a rule can unearth principal aspects of how the rule affects the operation studied. In addition, whether the rule that today limits operational areas for naval vessels adheres to the intentions of how seaworthiness is defined by the Swedish Ship Safety Law<sup>78</sup> can be questioned, i.e., does the rule consider the purpose and intended use of the vessels?

## Discussion

The presented investigation analyses the level of safety in general for the 1990–2015 period. The analyses performed by the Swedish Accident Investigation Board and the Armed Forces after incidents fill the role of expert assessments. Several suitable areas for in-depth studies are only discussed briefly. By adhering to the FSA structure, most of these areas could be studied more in-depth, particularly with a proactive approach using simulations, analytical models and expert groups from the Armed Forces to identify effective safety measures with acceptable and / or low operational impact (cost), i.e., the possibility with the FSA could be greater than what is found here.

The investigation described was performed independently from the Swedish Armed Forces. The findings were presented to the Swedish Navy and the Military Maritime

Safety Inspectorate. It has not been the role of this work to follow up on how, and if, the recommendations and lessons identified were implemented into rules and practices.

The IMO's work is geared toward civilian shipping. Most regulations explicitly exclude military vessels and other vessels of state. However, the tradition of how to understand maritime safety does affect, formally and informally, vessels outside the IMO's scope such as military vessels. This leads to a need to be able to investigate when and if this effect should be allowed to influence rules and design. By using the lessons identified here, an organization can better define the expectations of an FSA-based approach, the data needed, and how they should be reported to facilitate a systematic and structured analysis.

The case examined raises many questions such as about how to articulate the actual difference between civilian and military contexts, especially in peace time; about how risk to individuals should and could be compared to national security risks as a result of operational limitations put on armed forces; and about how different types of hazards combine to create risk. These types of questions that are dependent on the connections between the organizations and technology under study and the Swedish society in general are largely here left unanswered. However, answering such questions without concrete examples easily becomes abstract and will therefore not affect decision makers.<sup>79</sup>

The hope here is that the case studied and described can be used as *one* example that together with other suitable and complementing examples can assist in making future conclusions that assist decision makers and increase the understanding of applicability and validity of risk management in state safety and security issues. However, it is unlikely that the perspective on risk presented by the

FSA alone can answer such important and complex questions. Compared to traditional risk analysis of technical systems the FSA covers more aspects of the socio-technical system studied. However, the analysis power provided is not, and not intended to be, an approach that can be said to fully represent risk and safety in socio-technological systems.<sup>80</sup>

Also more specifically in relation to this case further work, both in regard to how central parameters should be measured or calculated and more overarching questions, is needed. In relation to the definition of central parameters, it is important that such definitions (such as how to calculate the number of ship years) are clear and communicated. Two overarching questions that need further investigation are how risk limits in relation to military tasks should be defined and how to define and assess operational costs in general and quantitatively.

The extra risk introduced by antagonistic threats is not assessed, and the crews have not been tested in relation to such conditions. This finding could mean that the negative effects of the rule (as a result of the civilian and commercial background), which remove the crews' need for continuous risk assessment on-board, could be much more harmful to war-like military operations than what is shown in the material studied.

Different types of rules interact and are affected by the purpose and intended use of the vessels differently. The lessons identified here, particularly in relation to the rule on the sea area of safe operation, are not necessarily generalizable to other areas of regulation. However, the applicability of the FSA structure is, with more certainty, generalizable to other areas, as the lessons learnt in this case are also supported by other applications and descriptions of the FSA.

## Conclusions

In the period studied, there have been safety issues leading to risks higher than negligible. For the studied severe accidents, the identified risk levels are a result of decisions made on-board when solving military peacetime tasks. However, the quantitative analysis of the nine severe accidents shows that human factors affect the probability of an incident; furthermore, human factor strengths can and must be included, as they can be important to understanding the link from incident to consequence. The less severe incidents leading to injuries were most often a result of maintenance work performed on-board independent of the vessel operation.

An approach such as the FSA is useful and needed also by organizations outside the traditional focus of the IMO. The investigation shows that an investigation as performed here analyses both the effectiveness and the effects of the rule. This observation means that an analysis can show if a rule affects safety in the manner intended and if there are other means by which the rule affects the operations.

This investigation has shown that the recommendations to change the sea area rule and the implementation led to a rule that has very limited positive effects, and possible far-reaching negative effects on safety culture and substantial operational costs.

In general, it is therefore concluded that the proactive perspective of the FSA investigation of a rule can unearth principal aspects of how a rule affects the operation studied.

The author has a PhD in Shipping and Marine technology and is an assistant professor in Military-Technology at the Swedish National Defence University.

## Acknowledgments

The study was funded by the Swedish National Defence University ([www.fhs.se](http://www.fhs.se)) and was facilitated by the data and reports shared by the Swedish Navy.

## Notes

1. James, Paul: *Use of class and standards for assurance*, paper presented at the Warship 2010: Advanced Technologies in Naval Design and Construction, London 2010; Liwång, Hans; Ringsberg, Jonas W. and Norsell, Martin: "Probabilistic risk assessment for integrating survivability and safety measures on naval ships", *International Journal of Maritime Engineering*, vol. 154, 2012, pp. A21-A30.
2. *Regler för militär sjöfart 2013 (Swedish military ship code 2013)*, The Swedish Armed Forces Head Quarters, Stockholm 2013.
3. *Revised guidelines for formal safety assessment (FSA) for use in the IMO rule-making process (MSC-MEPC.2/Circ.12)*, International Maritime Organization, IMO, London 2013.
4. Ibid.
5. Boulougouris, Evangelos K. and Papanikolaou, Apostolos D.: "Risk-based design of naval combatants", *Ocean Engineering*, vol. 65, 2013, pp. 49-61; op. cit., Liwång, Hans et al., see note 1; Liwång, Hans and Jonsson, Henrik: "Comparison between different survivability measures on a generic frigate", *International Journal of Maritime Engineering*, vol. 157, 2015, pp. A125-A134.
6. *Regler för militär sjöfart 2013, Del RMS-D Drift (Swedish military ship code 2013, Part RMS-D Operations)*, The Swedish Armed Forces Head Quarters, Stockholm 2013.
7. *COUNCIL DIRECTIVE 98/18/EC of 17 March 1998 on safety rules and standards for passenger ships*, The Council of the European Union, Brussels 1998.
8. Wikingsson, Jon: "Ett örlogsfartyg är inte ett bestyckat handelsfartyg (A warship is not an armed merchant ship)", *Tidskrift i sjöväsendet*, vol. 1, 2011, pp. 11-22.
9. Skjong, Rolf: "Regulatory framework", in Papanikolaou, Apostolos D. (ed.): *Risk-based ship design*, Springer-Verlag, Berlin 2009, pp. 97-151.
10. Liwång, Hans; Ericson, Marika and Bang, Martin: "An examination of the implementation of risk based approaches in military operations", *Journal of Military Studies*, vol. 5(2), 2014, pp. 50-67.
11. *Försvarsmaktens gemensamma riskhanteringsmodell (The Armed Forces joint risk management model)*, The Swedish Armed Forces, Stockholm 2009, p. 12.
12. Ibid., p. 62.
13. *Formal safety assessment, Decision parameters including risk acceptance criteria, Submitted by Norway (MSC 72/16)*, International Maritime Organization, IMO, London 2000; op. cit., *Regler för militär sjöfart 2013*, see note 2.
14. The EU Commission's Sixth Framework Programme as described by Juhl, Jeppe Skovbakke: "Risk-based approval", in Papanikolaou, Apostolos D. (Ed.): *Risk-based ship design*, Springer-Verlag, Berlin 2009, pp. 153-194; Sames, Pierre C.: "Introduction to risk-based approaches in the maritime industry", in *ibid.*, pp. 1-15; Vassalos, Dracos: "Risk-based ship design", in *ibid.*, pp. 17-96; op. cit., Skjong, Rolf, see note 9.
15. See examples of such analysis in Evans, Andrew W.: *Transport fatal accident and FN-curves: 1967-2001*, University College London, London 2003.
16. Op. cit., *Revised guidelines for formal safety assessment*, see note 3; Loughran, Colin G.; Pillay, Anand; Wang, Jin; Wall, Alan and Ruxton, Tom: "A preliminary study of fishing vessel safety", *Journal of Risk Research*, vol. 5(1), 2002, pp. 3-21; op. cit., Skjong, Rolf, see note 9.
17. Eliopoulou, Eleftheria; Papanikolaou, Apostolos D. and Voulgarellis, Markos: "Statistical analysis of ship accidents and

- review of safety level”, *Safety Science*, vol. 85, 2016, pp. 282-292; Praetorius, Gesa; Graziano, Armando; Schröder-Hinrichs, Jens-Uwe and Baldauf, Michael: ”FRAM in FSA—Introducing a Function-Based Approach to the Formal Safety Assessment Framework”, in Stanton, Neville A.; Landry, Steven; Di Bucchianico, Giuseppe and Vallicelli, Andrea (eds.): *Advances in Human Aspects of Transportation: Proceedings of the AHFE 2016 International Conference on Human Factors in Transportation, July 27-31, 2016, Walt Disney World®, Florida, USA*, Springer International Publishing, Cham 2017, pp. 399-411; Wang, Jin: ”Offshore safety case approach and formal safety assessment of ships”, *Journal of Safety Research*, vol. 33(1), 2002, pp. 81-115.
18. Rae, Andrew; Alexander, Rob and McDermid, John: ”Fixing the cracks in the crystal ball: A maturity model for quantitative risk assessment”, *Reliability Engineering & System Safety*, vol. 125, 2014, pp. 67-81.
19. Bakx, Gwendolyn C.H. and Nyce, James M.: ”Risk and safety in large-scale socio-technological (military) systems: a literature review”, *Journal of risk research*, vol. 20(4), 2015, pp. 463-481.
20. Op. cit., *Revised guidelines for formal safety assessment*, see note 3, p. 3.
21. *Ibid.*, p. 3.
22. Kontovas, Christos A. and Psaraftis, Harilaos N.: ”Formal Safety Assessment: A critical review”, *Marine Technology*, vol. 46(1), 2009, pp. 45-59; *FSA – dangerous goods transport with open-top containerships (MSC 87/INF.2)*, International Maritime Organization, IMO, London 2009; Lois, P; Wang, Jin; Wall, Alan and Ruxton, Tom: ”Formal safety assessment of cruise ships”, *Tourism Management*, vol. 25, 2004, pp. 93-109; op. cit., Loughran, Colin G. et al., see note 16.
23. Op. cit., Kontovas, Christos A. et al., see note 22.
24. Op. cit., *Revised guidelines for formal safety assessment*, see note 3.
25. *Ibid.*, p. 5.
26. *Ibid.*, annex, p. 6.
27. *Vägledning för risk- och sårbarhetsanalyser (Guideline for risk and vulnerability assessments)*, The Swedish Civil Contingencies Agency, Karlstad 2011.
28. Op. cit., *Revised guidelines for formal safety assessment*, see note 3.
29. Op. cit., Vassalos, Dracos, see note 14.
30. Op. cit., *Revised guidelines for formal safety assessment*, see note 3.
31. *Ibid.*, p. 46.
32. Op. cit., *Vägledning för risk- och sårbarhetsanalyser*, see note 27.
33. Op. cit., *Formal safety assessment*, see note 13, annex 1.
34. *Ibid.*, annex 1.
35. *Ibid.*, annex 1.
36. *Ibid.*, annex 1.
37. *Ibid.*, annex 1.
38. *Ibid.*, annex 1.
39. *Ibid.*, annex 1.
40. *Ibid.*, annex 1.
41. *Ibid.*, annex 1.
42. *Ibid.*, annex 1.
43. *Säkerhetsinspektionen (The Military Safety Inspectorate)*, Swedish Armed Forces, <http://www.forsvarsmakten.se/sv/organisation/hogkvarteret/sakerhetsinspektionen/>. (2016-02-21)
44. Op. cit., *Regler för militär sjöfart 2013*, see note 2.
45. *Försvarsmaktens föreskrifter med arbetsordning för Försvarsmakten, FMArbo, (Armed Forces regulations with the rules of procedure for the Armed Forces)*, FFS 2016:2, The Swedish Armed Forces, Stockholm 2016.
46. Op. cit., *Regler för militär sjöfart 2013*, see note 2.
47. Hjort, Patric: ”Design för överlevnad (Design for survivability)”, *Tidskrift i sjöväsendet*, vol. 5, 2008, pp. 357-365; op. cit., Wikingsson, Jon, see note 8.
48. Op. cit., *Regler för militär sjöfart 2013*, see note 2.
49. *Naval ship code, ANEP 77*, NATO Standardization Agency, Brussels 2010; Simpson, Robert M.: ”Implications of the NATO Naval Ship Code”, paper presented at the Warship 2010: Advanced Technologies in Naval Design and Construction, London 2010.
50. Op. cit., Liwång, Hans et al., see note 1.
51. Op. cit., Boulougouris, Evangelos K. et al., see note 5; op. cit., Liwång, Hans et al., see note 1; op. cit., Liwång, Hans et al., see note 5; op. cit., Simpson, Robert M., see note 49.
52. Op. cit., *COUNCIL DIRECTIVE 98/18/EC*, see note 7.
53. *Ibid.*, p. 2.
54. *Ibid.*, p. 3.
55. *Ibid.*, p. 7.

56. Kuo, Chengi: *Safety management and its maritime application*, The Nautical Institute, London 2007; Grech, Michelle Rita; Horberry, Tim John and Koester, Thomas: "Organization, society and culture", *Human factors in the maritime domain*, CRC Press, Boca Raton 2008.
57. Op. cit., *Regler för militär sjöfart 2013*, see note 6.
58. *Olycka med Stridsbåt 90H, nr 848, syd Hammudden, Utö, AB län, den 24 oktober 2006 (Rapport RM 2008:02) (Accident with combat boat 90H, # 848, south Hammudden, Utö, October 24 2006 (Report RM 2008:02))*, The Swedish Accident Investigation Authority, Stockholm 2008.
59. Op. cit., *Regler för militär sjöfart 2013*, see note 6.
60. Op. cit., *Olycka med Stridsbåt 90H*, see note 58; *Sjöolycka 1991-11-14 Kollision i Södra kvarken mellan kustflottans robotbåtar HMS Nynäshamn och HMS Luleå (Ärende S-11/91) (Marine accident 1991-11-14 Collision in Södra Kvarken between the missile boats HMS Nynäshamn and HMS Luleå (Case S-11/91))*, The Swedish Accident Investigation Authority, Stockholm 1992; *Olycka med en stridsbåt 90H den 15 juni 1999 söder om Rosenholmsvarvet, Karlskrona, K län (Rapport RM 2000:02) (Accident with a combat boat 90H on June 15 1999 south of Rosenholmsvarvet, Karlskrona (Report RM 2000:02))*, The Swedish Accident Investigation Authority, Stockholm 2000; *Grundstötning med Stridsbåt 90 H nr 881 vid St Brorn, O län, den 25 april 2003 (Rapport RM 2004:01) (Grounding with combat boat 90H number 881 at St Brorn on April 25 2003 (Report RM 2004:01))*, The Swedish Accident Investigation Authority, Stockholm 2004; *Kollision mellan två stridsbåtar 90H, norr om Sollenkroka brygga, Vindö, AB län, den 13 juni 2004 (Rapport RM 2006:01) (Collision between two combat boats 90H, north of Sollenkroka, Vindö, June 13 2004 (Report 2006:01))*, The Swedish Accident Investigation Authority, Stockholm 2006; *Olycka vid utbildning i mörkernavigering då en G-båt ur Försvarmakten kolliderade med en boj den 1 oktober 2014 vid Klövholmsgrund. (Rapport RM 2016:01) (Accident at training of navigation during darkness when a G-boat from the Swedish Armed Forces collided with a buoy on October 1 2014 at Klövholmsgrund (Report RM 2016:01))*, The Swedish Accident Investigation Authority, Stockholm 2016; *Skjutolycka vid Stora Skogsskär, Utö skjutfält 2008-05-20 (Bilaga 1 till 14 990:63170) (Shooting accident at Stora Skogsskär, Utö firing range 2008-05-20 (Appendix 1 to 14 990:63170))*, The Swedish Armed Forces Investigation Commission, Stockholm 2008; *Sjöbelastnings- och förtöjningsskador på HMS Malmö (Wave induced damage and mooring damage to HMS Malmö)*, The Military Maritime Safety Inspectorate's Investigation Commission, the Swedish Armed Forces, Stockholm 2009; *Rapport stridsbåt 831 (HKV 14 930:57229) (Report Combat Boat 831 (HKV 14 930:57229))*, The Swedish Armed Forces Head Quarters, Stockholm 2010.
61. *Försvarmaktens årsredovisning 2004 (The Swedish Armed Forces annual report 2004)*, The Swedish Armed Forces, Stockholm 2005; *Försvarmaktens årsredovisning 2011 (The Swedish Armed Forces annual report 2011)*, The Swedish Armed Forces, Stockholm 2012; *Försvarmaktens Årsredovisning 2014 (The Swedish Armed Forces Annual Report 2014)*, The Swedish Armed Forces, Stockholm 2015.
62. Paté-Cornell, M. Elisabeth: "Uncertainties in risk analysis: Six levels of treatment", *Reliability Engineering & System Safety*, vol. 54(2-3), 1996, pp. 95-111; Abrahamsson, Marcus: *Uncertainty in quantitative risk analysis – characterisation and methods of treatment*, Thesis, Doctor of Philosophy, Lund University, Lund 2002; Liwång, Hans: "Survivability of an Ocean Patrol Vessels – Analysis approach and uncertainty treatment", *Marine Structures*, vol. 43, 2015, pp. 1-21.
63. Op. cit., *Olycka med Stridsbåt 90H*, see note 58; op. cit., Swedish Accident Investigation Authority 1992, 2000, 2004, 2006, 2016, see note 60; op. cit., Swedish Armed Forces 2008, 2009, 2010, see note 60.
64. Op. cit., *Formal safety assessment*, see note 13.
65. Op. cit., *Försvarmaktens Årsredovisning 2014*, see note 61.
66. Op. cit., *Formal safety assessment*, see note 13.
67. Based on the operational cost of the Swedish Navy for 2014 according to the Swedish Armed Forces, op. cit., *Försvarmaktens Årsredovisning 2014*, see note 61.

68. Op. cit., Skjong, Rolf, see note 9.
69. Op. cit., Rae, Andrew et al, see note 18;  
Goerlandt, Floris; Khakzad, Nima and  
Reniers, Genserik: "Validity and validation  
of safety-related quantitative risk analysis: A  
review", *Safety Science*, vol. 99 part B, 2017,  
pp. 127-139.
70. Op. cit., Rae, Andrew et al, see note 18.
71. Op. cit., *Olycka med Stridsbåt 90H*, see note  
58, p. 53.
72. *Ibid.*, p. 54.
73. Op. cit., Eliopoulou, Eleftheria et al., see  
note 17.
74. Op. cit., Praetorius, Gesa et al. see note 17.
75. Op. cit., Wang, Jin, see note 17.
76. Op. cit., Boulougouris, Evangelos K. et al.,  
see note 5.
77. Op. cit., Liwång, Hans et al., see note 5.
78. *SFS 2003:364 Fartygssäkerhetslagen (The  
ship safety law)*, 2015.
79. Liwång, Hans: "Risk communication within  
military decision-making: pedagogic consid-  
erations", *Defense & Security Analysis*, vol.  
33(1), 2017, pp. 30-44.
80. For a discussion on the demands on such ap-  
proaches see op. cit., Bakx, Gwendolyn C.H.  
et al., see note 19.