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The interconnectedness between efforts to reduce the risk related to accidents and attacks - Naval examples

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Abstract

Fatalities on board military vessels are the result of different types of incidents, including both accidents and antagonistic attacks. The aim of this study is to identify aspects that determine the safety and operability of military vessels from a sociotechnical perspective. Safety is studied in relation to four different types of operations: the Falklands War in 1982, antagonistic attacks in situations other than war from 2000 to 2012, submarine incidents from 2000 to 2015, and severe accidents involving military vessels in Norway and Sweden from 1990 to 2015. For the incidents analyzed, the study identifies qualitative aspects that contributed to the outcome and consequences of the incident and, if possible, the risk level. The importance of organizational and management safety issues, personnel safety issues and design safety issues are analyzed. The study shows that different operational types have different risk levels but, to some extent, the same types of safety issues. In general, risk is high when the ship is not prepared and managed for war; the recoverability, i.e., the ability to limit consequences, is an important safety factor in all of the operational types studied. The probability of an incident occurring is governed by management decisions, and the recoverability is governed by the capacity for effective crew actions despite limited management. The presence of external threats leads to a need for extra levels of system understanding, for management and for personnel.

Key words: Naval ship; Safety; Survivability; Security; Risk level; Accident; Attack; Sociotechnical systems

1. Introduction

The protection from accidents and attacks is often regarded as separate concepts (G. Bakx & Nyce 2016). However, the links between attacks and accidents could possibly reveal important mechanisms related to safety and security. Severe consequences on board military vessels have historically been the result of several different types of incidents, including both accidents and antagonistic attacks, during peacetime and during war. Accidents and attacks not only lead to fatalities but also directly and indirectly affect operations. Therefore, it is important to work structurally with all these challenges to identify effective measures that increase safety and survivability. Lives, effectiveness and freedom of action should be protected, and safety in this study includes consequences resulting from accidents and antagonistic attacks. The aim is to support a long-living organization that can achieve its goals. Therefore, a suitable definition for safety in this context is the ability of organizations to deal with risks, hazards and threats to avoid damage or losses yet still achieving their goals[1]. Of special interest for this study is the relationships between different types of hazards and threats. These relationships cannot be described by studies limited to only accidents or only survivability after antagonistic attacks. The understanding of such relationships will assist in understanding the applicability and relative importance of approaches, methods and tools developed in the safety or security arena.

Today there a widespread understanding that there is a need for system thinking for creating safety and that accidents should be seen as systems failures, as opposed to a result of human errors (Hollnagel

[1] Developed from "safety is the ability of individuals or organizations to deal with risks and hazards so as to avoid damage or losses yet still achieve their goals" (Reason 2000).

2012; Leveson 2004; Rasmussen 1997). Based on such an approach safety research on civilian ships has shown that “the widespread confidence in the efficacy of new or improved technical regulations … has led to a lack of awareness of complex interactions of factors and components in socio-technical systems” (Schröder-Hinrichs, Hollnagel, & Baldauf 2012). Therefore, Schröder-Hinrichs et al. (2012) argue that safety improvements need to shift focus from a technology-centered perspective to sociotechnical aspects. Such sociotechnical lessons are not documented for large scale military systems (G. C. H. Bakx & Nyce 2015). “It is the system that need to be improved. Isolated discussions on single actors and single causes…will not lead to sustainable system improvements” (Schröder-Hinrichs et al. 2012). Therefore, the aim of this study is to identify aspects that determine the safety and operability of military vessels from a sociotechnical system perspective.

To capture the diversity of military ship operations, this study examines four operational situations that together describe different aspects of the life of a military vessel. The operational situations investigated are the Falklands War in 1982, examples of antagonistic attacks in situations other than war from 2000 to 2012, submarine incidents from 2000 to 2015 and severe accidents involving military vessels in Norway and Sweden from 1990 to 2015. For the incidents analyzed, the study identifies qualitative factors that have contributed to the outcome and consequences of the incidents and, if possible, the risk level. Based on the identified qualitative factors, the importance of Organization and management, personnel and effects of design are analyzed in relation to the framework presented in Section 2.3 Framework for analysis.

2. Theory and approaches

Within the field of safety science models to explain accident causation in safety-critical domains have seen an evolution of the understanding of causes and effects. From that failures were understood as failure of hardware via human error at the so called sharp end to a focus on latent organizational causes. Accidents are now widely acknowledged to be a system phenomenon (Dallat, Salmon, & Goode 2019). However, the understanding of security has seen no such a systematic development and the protection from accidents and attacks is often regarded as separate concepts (G. Bakx & Nyce 2016). By not examining the links related to effects and measures between attacks and accidents several different important mechanisms related to military activity are omitted from the development of new knowledge. Such links include examples where measures to avoid attacks increase the probability of accidents and the risk increase during military training and exercises and the risk reduction the same activity have on military operations (Johnson 2012a, 2012b; Liwång 2018). This creates theoretical challenges for this study, especially given the fact that most of the available research focuses on routine activity while military systems and organizations are designed for the extraordinary. This despite that “security disaster and accidents seems to emerge in much the same ways” and that there should be benefits from connecting work related to accidents to work related to attacks (G. Bakx & Nyce 2016). However, neither the safety literature nor the security literature provide approaches tailored for studying this interconnectedness between work related to accidents and work related to attacks (G. Bakx & Nyce 2016) and therefore the scientific understanding presented by existing studies cannot be assumed to be complete.

2.1 Maritime safety

Here safety is regarded as an inherent characteristic of system performance that only can be revealed through the analysis of the system as a whole. This, sometimes called ‘new view’ or ‘system view’ of safety, has much in common with socio-technical system perspectives (G. C. H. Bakx & Nyce 2015; Dallat et al. 2019) and the cognitive systems engineering perspective, primarily interested in the relationships between human and organizational issues and systems failure (Baxter & Sommerville 2011). The aim of this approach is to assist in the explanation of systems failures and not only a limited description of human errors (Hollnagel 2012; Leveson 2004; Rasmussen 1997). From this

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perspective on safety it has for civilian ships been identified that incidents to a large extent can be explained by management aspects.

According to Schröder-Hinrichs et al. (2012), this is a result of the fact that "work environments…are dominated by socio-technical systems that defy time-honored methods and familiar ways of thinking", but it has also been found that civilian crews are underestimating risks in dangerous situations where they have been successful in the past (Schröder-Hinrichs et al. 2012). Safety issues in this study are divided into three themes, as suggested by Hetherington, Flin, and Mearns (2006), based on common sociotechnical themes for maritime accidents: organization and management, personnel and effects of design. Schröder-Hinrichs et al. (2012) present six sociotechnical issues that are used here as examples for the three themes. The three principle themes are presented in Figure 1.

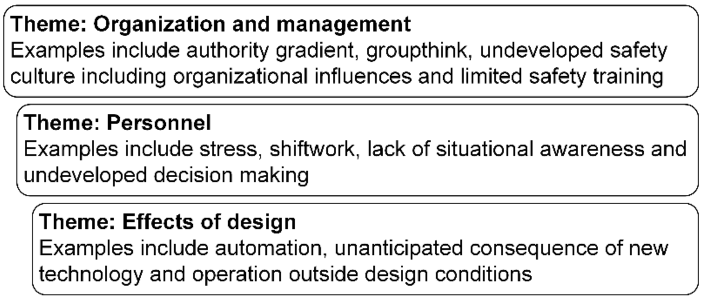

Fig 1 Safety themes and examples of sociotechnical issues for maritime safety. Developed from Hetherington et al. (2006) and Schröder-Hinrichs et al. (2012)

Below, the themes from Figure 1 are given a short introduction.

The themes "organization and management" includes issues related to organizational behavior (Hetherington et al. 2006) such as authority gradient, groupthink and the desire for harmony, organizational influences (latent conditions) and efficiency-thoroughness trade-off (Schröder-Hinrichs et al. 2012). Other management issues include ineffective maintenance and crew competence which affects reliability and therefore also safety (Mokashi, Wang, & Vermar 2002). Crew competence and onboard management can thus affect safety incidents indirectly via the quality of maintenance, which can affect the probability of incidents as well as recoverability and rescue work after an incident.

The theme "personnel" human performance factors or behaviors that can contribute to incidents (Hetherington et al. 2006) and includes examples such as situational awareness and decision making and the effects of factors such as stress and shiftwork (Hetherington et al. 2006; Schröder-Hinrichs et al. 2012). Consequently, it is important that the ship operator acknowledges that well-learned skills and well-rehearsed tasks require less attentional control; thus, the performance of these tasks is less affected by stressors, and the crew therefore maintain more control over the task at hand in high-risk situations (Beilock, Carr, MacMahon, & Starkes 2002). The International Maritime Organization (IMO) has identified that improving the training of seafarers is one of the most important ways to decrease many human element issues (Emad & Roth 2008).

The theme "effects of design" include issues related to areas such as automation of the onboard tasks and the unanticipated consequences of new technology (Schröder-Hinrichs et al. 2012). There is also a clear link between design and maintainability, and a low maintainability will create management challenges.

The system view of safety means that in order to have adequate models of incident causation a combination of aspects must be taken into account. This includes issues at the sharp end, such a chain of events at the time of the incident, issues as a result of design (at the blunt end) as well as latent system characteristics, such as organizational or management issues. Also, in this study the analysis of safety issues (with negative effect on safety) will also be completed with an analysis of safety factors which have positive effect on safety as defined by Nisula (2014).

2.2 Safety and security in relation to military organizations and on naval ships

On board naval ships lifesaving (safety) cannot be limited to traditional maritime safety or to security. However, a large proportion of the performed studies on military organizations examine safety aspects of every day military activity, i.e., examines accidents that occur during peacetime activities such as exercises, training or standard patrols. Such studies include Stanton, Harvey, and Allison (2019), Read and Charles (2018) and O'Connor and Max Long (2011). There are also studies that investigate military operations in conflicts such as Martínez-Córcoles and Stephanou (2017), Moorkamp, Wybo, and Kramer (2016) and Rafferty, Stanton, and Walker (2013). However, all these studies have commonality in that they investigate safety issues emanating from within the studied organization. The external threat is best viewed as a stressor, but seldom the cause of the incident that the system must act on. There are therefore only a limited number of studies that specifically link safety related to accidents with the work related to attacks. Such examples include G. Bakx and Nyce (2016), G. C. H. Bakx and Nyce (2015), Johnson (2012a) and Worm, Jenvald, and Morin (1998),

In the military setting, both security and survivability relate to avoiding damage or losses yet still achieving goals, i.e., what here is called safety. Military doctrines typically define that security is achieved when measures are taken to protect one's forces and that appropriate security allows for freedom of action by reducing one's vulnerability to the actions of one's enemy (NATO 2007; University of Cincinnati 2004). Force protection is important for reaching security and is active operational measures that protect ships and groups of ships (NATO 2007). There is not a specific strong (scientific) safety perspective prevalent in the military literature. However, it is common to discuss the ships capability to deal with incidents in terms of survivability and dived the concept into susceptibility, vulnerability, and recoverability (Ball & Calvano 1994; Boulougouris & Papanikolaou 2013; Hughes 1995; Kim & Lee 2012; NATO 2012; Said 1995):

- Susceptibility is the inherent inability (including tactical measures) to avoid a hit, and it governs the probability of a weapon hit. Also includes force protection measures, such as fleet size and fleet composition (Harney 2010; Hughes 1995).
- Vulnerability is the inherent inability to resist damage, and it governs the probability of damage given a weapon hit.
- Recoverability is the ability to sustain operational capability, and it governs the probability of limiting or repairing damage and effects of damages.

Liwång (2016) shows that a technology focus in relation to external attacks may lead to design solutions with unnecessary high risk if the "relationship between the operation, design and risk is not understood". Liwång (2016) also identifies that aspects such as susceptibility can be effective for reducing risk and that ignoring these factors risks penalizing the system design options that may have positive effects on the ship's combat effectiveness. Important technical measures for survivability include redundancy and separation.

One specific difference between attacks and accidents that is highlighted in the literature is the relative importance of shipboard fires. Risk in relation to fire onboard is on a ship generally relatively low (Hakkarainen et al. 2009) also on naval vessels (Peters 2010). However, fire risk is the most common cause for loss of naval ships in relation to antagonistic attacks (Høyning & Taby 2000). Therefore, fire could be one aspects that differ substantially between accidents and incidents initiated by antagonistic attacks.

2.3 Framework for analysis

The framework used in the analysis is based on a system view of safety and a combination of the three civilian maritime safety themes described in Section 2.1 and the sequential perspective offered by understanding survivability as described in Section 2.2. This covers both proactive and reactive measures as well as capturing relevant perspectives on accidents as well as attacks and allows for examining both safety issues and safety factors. The analysis in Section 4 will be divided into the three themes organization and management, personnel and effects of design and for each theme susceptibility, vulnerability, and recoverability will be discussed. The focus is on the qualitative aspects of interactions between social and technical components. The analysis is aimed to identify both latent (organizational) safety issues as well as the course of events at the time of the incident.

In order to acknowledge that there could be different rationale behind the risk decisions taken onboard in different situations the study distinguishes between traditional maritime activity and activity called for by the specific roles of military ships, i.e., when the actions onboard such as speed, distance to other ships, sensor use and weapon use are affected by military tasks. The latter is here denoted activity called for by the military role of the ship.

The qualitative analysis will be supported by a quantitate analysis in relation to the risk level with the aim to be able to discuss the generalizability of the findings from the qualitative analysis. For the operational types for which the data is considered to be complete the quantitative analysis assess the societal risk level, defined as “average risk, in terms of fatalities, experienced by a whole group of people (e.g. crew, port employees or society at large) exposed to an … scenario” according to (IMO 2018). The level of societal risk; the Frequency – Number of fatalities (F_N) curve is given by

$$F_N = \sum_{j=N}^{N_{max}} f(N_j)$$

where $f(N_j)$ is the frequency per shipyear of N_j fatalities and N_{max} is the maximum number of fatalities. See (IMO 2018) for more information about the definition and assessment of societal risk and F_N diagrams. For such assessments the size of fleet at risk is measured by shipyears defined by the number of ships involved and the length in years of the period studied (IMO 2000, 2018).

3. Data

This study examines four limited areas that cover both war and peacetime operations that together could be said to define the operation of a military ship:

- Naval war, studied here with data from the Falklands War.
- Antagonistic attacks during peacetime operations, studied here with data from worldwide attacks (primarily terrorist and piracy attacks) from 2000 to 2012.
- Accidents during peacetime as a result of the specialized operational conditions created by military tasks, studied here with data from worldwide submarine incidents from 2000 to 2015 (North Korea and Iran are excluded. They are large submarine nations, but it is not realistic to assume that important incidents for these countries are known).
- Accidents during peacetime operations, studied here with data from severe accidents involving military ships in Norway and Sweden from 1990 to 2015.

The main data presented in this study is the qualitative data retrieved from the sources for each area. Additionally, for each area two or three cases are described in the text of this paper. However, the material studied is not limited to these cases or the aspects described herein. The qualitative analysis is based on the full source material; for more qualitative information, go to the respective source or set of sources.

The extent, completeness and richness of the source materiel varies between the four studied areas. In relation to naval war, submarine accidents and accidents during peacetime in Norway and Sweden the completeness of the data is considered to be relatively high in relation to ships lost and fatalities. In relation to antagonistic attacks during peacetime operations too few reliable sources have been found to be able to assess the possible completeness of the data. For the Falklands war non-conflict related fatalities (such as those resulting from a man overboard or illness) are not represented and for the other three areas the data on injuries is not complete.

3.1 The Falklands War

The description herein does not aim to capture the Falklands conflict in its entirety, for a more detailed operational description and to give a more tactile and realistic sense of what was at stake for those directly involved, it is recommended that readers review sources that describe the conflict more holistically and not limited to naval aspects. Table A1 describes the naval incidents of the Falklands War. The table is based on United Kingdom (UK) and Argentinian sources. The differences between the two sources are relatively small and primarily relate to the actual target of the Argentinian air strike on May 30th (Rivas 2012). Table A1 presents the UK version of that incident where no ship was hit in that attack. Qualitative and quantitative data is based on descriptions in Finlan (2004); Marsh (1983); Rivas (2012); Schulte (1994); Smith (1989) and Woodward and Robinson (1992).

The Falklands War includes a large variety of incidents, ranging from a single weapon hit without any significant consequences to the catastrophic effects of the torpedo hits on the ARA General Belgrano. Two specific incidents are selected here to describe several of the more severe situations encountered in naval war:

Case 1.A, The torpedoing of the ARA General Belgrano on May 2 (Table A1:#9). The attack resulted in 323 fatalities and 69 injured and the ship was lost. Before the attack, the ARA General was steaming south at a relatively even speed with two escort ships. None of the ships were using their sonars. The UK submarine the Conqueror fired three torpedoes. Two hit and detonated in contact with the ARA General Belgrano, while one hit the escort destroyer Hipolito Bouchard but did not detonate (Table A1:#10). The detonations on board the ARA General Belgrano spread quickly through the ship, suggesting that many watertight hatches were not closed. Power was lost to all systems on board and extensive damage to the watertight integrity of the vessel's hull made sinking inevitable. Nine-hundred persons were able to safely board the life rafts, and the ship sank approximately 45 minutes after the attack. The two escort ships, supported by several aircrafts, worked through the night and the following day searching for and rescuing the ARA General Belgrano's crew from the cold water. However, the start of the rescue work was delayed because the abandonment and total loss of the ARA General Belgrano was not immediately known. Approximately 770 persons were rescued from the water (Rivas 2012; Smith 1989; Woodward & Robinson 1992).

Case 1.B, Air strike/bomb on the HMS Coventry on May 25 (Table A1:#34). The attack resulted in 19 fatalities and 30 injured; the ship was lost. The HMS Coventry was attacked after several days of air attacks and immediately followed an attack on the HMS Broadsword. The UK anti-aircraft missiles had trouble locking on to the approaching aircrafts, especially those close to shore, and the coordinated attack on the two ships made their protective posture much weaker. At least three bombs hit the HMS Coventry, started fires, and created a large hole in the port side. The crew abandoned ship and were picked up by the HMS Broadsword (Rivas 2012; Smith 1989; Woodward & Robinson 1992).

Observations related to cases 1.A and 1.B. There was a large difference in preparedness between the two ships. The HMS Coventry, together with the HMS Broadsword, were actively trying to fight off

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the attack, and the ships had together shoot down 5 Argentinian aircrafts earlier in the day. The ARA General Belgrano was protected by an escort, but no action was taken to use this protection. Reports also suggest that the onboard preparedness of the ARA General Belgrano was low. The effort needed to sink the ships was therefore very different, and the number of lives lost also differed, with the UK forces seeing fewer fatalities as a result of their higher readiness and better use of available resources. A qualitative analysis of the naval warfare also shows relatively large differences in how recoverability was managed between the ships.

The material on the Falklands War also shows that there are often multiple attacks delivered in waves over the course of a single attack mission. There was also a strategic layer of management that affected the incidents. How the two navies had adopted technology into their strategies, whether they had access to specific ship types, and how they used different ship types, to a large extent, affected the type and number of incidents (Finlan 2004). For example, the deployment of UK submarines and their sinking of the ARA General Belgrano meant the end of the Argentinian Navy's involvement in the war (Finlan 2004). For both sides, the implementation of modern technology meant significant reductions in the available time for reaction to incoming threats (Finlan 2004; Woodward & Robinson 1992).

Table A1 sums up the 491 fatalities and 295 injured, not counting single accidents such as a man overboard. The fleet at risk included approximately 20 Argentinian ships and 100 to 150 UK ships (Smith 1989). Given the duration of the war and the various ships' operational activities, this adds up to approximately 19 shipyears. In total, 41 percent of attacks led to a vessel being lost or abandoned, and almost 40 percent of the incidents led to fires.

The quantitative analysis also shows that a ship can be hit by a weapon without fatalities and that in general, a larger crew leads to both a greater strain on other vessels in life-saving efforts and to a larger number of fatalities. Additionally, it can be identified that effective and timely response is critical in life-saving efforts; and that the ability and capacity to prevent large-scale fire and flooding is vital to recoverability.

3.2 Antagonistic attacks other than war 2000-2012

Antagonistic attacks in situations other than war are set in shifting operational contexts. Therefore, it is not possible to summarize the operational conditions. The attacks in Table A2 are the result of situations such as national conflicts, terrorism, piracy and crime in general. The urgency of the cases presented is typically high but often localized. Qualitative and quantitative data is based on descriptions in IMB (2011); King (2013); Langworthy, Sabra, and Gould (2004); Republic of Korea (2010) and US Department of Defense (2001). Two specific incidents have been selected to capture the essence of some of the more severe situations encountered in situations other than war:

Case 2.A, The Improvised Explosive Device (IED) Attack on the USS Cole in 2000 (Table A2:#2). The attack resulted in 17 fatalities and 39 injured. The USS Cole was attacked while refueling and moored to a dolphin off the port of Aden, Yemen. Approximately 60 persons were directly affected by the blast, and approximately 16 of the 17 fatalities occurred in the immediate aftermath of the blast. Despite the fact that the ship's main medical facility was destroyed by the blast, it was still possible to treat those injured on board. Local hospitals and more distant military hospitals were also used. The efforts made on board and through external assistance were extensive and managed to limit the consequences of the blast for the crew and ship (Langworthy et al. 2004). The official lessons learned related mainly to the risk management and threat assessment performed before an incident (US Department of Defense 2001).

Case 2.B, The torpedoing of the ROKS Cheonan in 2010 (Table A2:#12). The attack resulted in 46 fatalities and a total loss of the vessel. The corvette was sunk when the ship was on patrol duty in the

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territorial waters of the Republic of Korea, 2.5 km off the southwestern coast of Baekryong Island. The sinking was the result of a large underwater explosion beneath the ship suspected to be the result of a torpedo. The ship was torn into two pieces and sank in less than ten minutes, however, there was no evidence of a fire on board. Approximately 60 persons were saved by other naval ships in the area (Cha 2010; Republic of Korea 2010).

Observations related to cases 2.A and 2.B. The two attacks were performed close to shore; this was also the case for a large proportion of all attacks identified. There are most likely several reasons for this: attacks close to shore are easier to perform and are more likely to succeed), however, attacks far from shore are also easier to keep classified. Both attacks are examples of very powerful attacks.

The material on attacks in other situations than war also shows the importance of having the ability and capacity to slow down or stop large–scale fire and flooding. However, after the attacks, it is typycally possible to focus on life-saving efforts as a result of the limited continuity of the external threat and because there was often external support available. The fact that many attacks occur close to shore (in port or close to port) also has a positive effect on the availability and timeliness of external support.

Table A2 reflects 143 fatalities and 43 reported injured in 18 incidents. Approximately 30 percent of the ships that were hit were lost or abandoned. A large percentage of the incidents led to fires.

3.3 Submarine incidents worldwide during the time period 2000-2015

Submarine operations are, by their nature, clandestine and “have always been inherently dangerous” as a result of operations “in shallow, congested waters and in close proximity of competitor submarines and surface ships; constantly changing weather and acoustic conditions; high-pressure steam and other energetic systems” (Konetzni 2009). The aim here is to describe qualitative and quantitative data on Submarine incidents. The data is based on descriptions in Associated Press (2006); Australian Maritime Digest (2009); Brannon (2003); Bussert (2003); Chivers and Drewaug (2005); Defense Daily (2003); Dettmer and Harder (2000); Federal Information & News Dispatch (2013); Grace (2012, 2013); IDRW News Network (2015); Interfax (2013a, 2013b); Konetzni (2009); Luther (2006); Mumbai Mirror (2010); Munsey (2002); Munsey and Hegh (2003); Nordenman (2007); Pugliese (2006); Sea Power (2002); Tringham (2012); US Fed News Service (2005a, 2005b, 2007a, 2007b, 2008, 2009, 2010); Wilcock (2011); Willett (2005) and Zarakhovich (2003).

Case 3.A, The sinking of the submarine Kursk as a result of a torpedo accident in 2000 (Table A3:#1). There were 141 fatalities. The Russian nuclear submarine Kursk sank after an onboard explosion and subsequent detonations in the forward part of the hull. At the detonation almost all compartments of the submarine got damaged and a large part of the crew died instantly in these compartments. 12 persons were able to survive in the aft part of the ship. They have supplies to survive for several days and also had equipment to clean out corbondioxid in the air. Found notes indicated that they were alive 14 hours after the accident. An accidental fire caused by the air cleaning equipment led to deaths of the 12 persons before the rescue operations were able to reach the submarine. (Brannon 2003; Nordenman 2007)

Case 3.B, The sinking of the K-159 submarine from leakage during towage in 2003 (Table A3:#10). There were nine fatalities. The Russian nuclear submarine K-159 was being towed to a navy scrap yard when it sprang a leak and went down in the Barents Sea in the waters between Russia and Norway. Nine sailors lost their lives. There are no public sources describing any rescue efforts. (Zarakhovich 2003)

Case 3.C, Man overboard incident from the USS Minneapolis St. Paul submarine in 2006 (Table A3:#17). There were two fatalities. Four crew members from the USS Minneapolis St. Paul fell

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overboard in an accident in rough weather as the vessel left Devonport in Devon. The four were pulled from the water by the submarine crew. Two were pronounced dead after being taken to the hospital. Civilian boats and a Royal Navy rescue helicopter took part in the rescue work. (Campbell 2006)

The material on submarine incidents shows a large variety of type of incidents and the publicly available information is limited for most submarine accidents. The resources available for rescue work are limited compared to surface ship incidents. The incidents indicate that the combination of a large concentration of energy such as batteries, fuel and munitions with limited escape routes and subsurface operations lead to relatively large consequences. Table A3 reflects a total of 275 fatalities and 5 submarines lost or abandoned. One fourth of the accidents in Table A3 are fires, one fourth are collisions and one fourth are groundings. The data includes one antagonistic attack: the arson on board the USS Miami by disgruntled shore personnel (Grace 2013). The estimated fleet at risk is 430 submarines per year when North Korea and Iran are excluded (Global Firepower 2019).

3.4 Military maritime accidents in Norway and Sweden 1990-2015

Norway and Sweden are chosen because they represent two nations where severe incidents can be assumed to have been released to the public. The two nations' incidents, as described in Table A4, are to be seen as a base rate reference for the other three operational types discussed. Qualitative and quantitative data is based on descriptions in Ekanger (2014); NTB (2006); Swedish Accident Investigation Authority (1992, 2000, 2004, 2006, 2008, 2016) and Swedish Armed Forces (2008, 2010).

Case 4.A, The collision between the HMS Luleå and the HMS Nynäshamn in 1991 (Table A4:#1 and #2). There was one fatality. From November 11-14, the Swedish navy conducted a major exercise that was the end of two weeks of scheduled drills. On 13 and 14 November. The HMS Luleå and HMS Nynäshamn performed a night–time attack exercise together with one additional ship. The operation ended with the three vessels divided into two raids carrying out fictitious torpedo attacks with combat-related behavior, which meant limited radio traffic and only intermittent radar transmission. The attacks were performed at high speeds in excess of 30 knots. The lookout service was challenged by the breaking seas and heavy wind. When the HMS Luleå had completed its attack, it reduced speed to approximately 10 knots. When the HMS Nynäshamn was in the final stage of the attack, the officer in of the ship observed what he seconds later understood was the aft lantern of the HMS Luleå. The distance between the two vessels was then very short, so the control officer ordered the helmsman to turn starboard in a collision avoidance maneuver. However, the short distance and high speed led to a heavy collision that immediately killed one person on board the HMS Luleå. Additionally, both vessels received extensive damage during the collision but managed to reach port under their own power after the damages were inspected (Swedish Accident Investigation Authority 1992).

Case 4.B, The Norwegian frigate KNM Oslo's grounding in 1994 (Table A4:#3). There was one fatality. As the result of a mechanical failure, the frigate drifted in heavy seas before eventually drifting aground. The grounding created large, sudden and violent motions of the vessel, and as a result two crew members fell overboard. Both crewmembers made attempts to obtain towlines from other ships. One of the two was rescued by a nearby civilian boat after a couple of minutes, however, the other was found dead after extensive search efforts. Several additional crewmembers were injured due to the frigate's high acceleration at the time of the grounding. The crew was taken ashore by rescue helicopters and boats. The frigate later sunk while being towed (Ekanger 2014; NTB 2006).

Case 4.C, The Swedish combat boat 820's collision with land at high speed in 1999 (Table A4:#6). Seven out of the eight crewmembers on board were injured, four seriously, however, there were no fatalities. The boat was traveling at high speed, transporting spare parts and personnel during daylight hours in familiar waters. While performing a tight turn the vessel collided with a fixed concrete object. The boat was severely damaged. The exact cause of the accident could not be identified despite an extensive investigation. It was theorized that the cause could have been a result of limited maneuverability due to a lack of maintenance of the hydraulic steering. Others believed it may have been the result of misjudgment by the driver, or a combination of these causes. It was determined that the injuries sustained by the crew could have been limited had they used the seatbelts. After the collision, the personnel with limited injuries tended to those in more critical condition and called for assistance from other combat boats in the area. Within ten minutes, additional assistance arrived at the scene, and began tending to the injured and inspecting the damage sustained to the vessel. After approximately 20 minutes, the vessel was towed to a position where injured personnel could be transported to the local hospital by ambulance (Swedish Accident Investigation Authority 2000).

Observations related to cases 4.A, 4.B and 4.C. The number of personnel on board was in excess of the minimum required crew needed for navigation. Also, the actions taken by personnel on board following the accidents indicate a high level of training and skill in relation to life-saving and recoverability. Therefore, the capability to limit secondary consequences of accidents was high. Case studies, 4.B and 4.C are not considered to be a result of activities called for by the military role of the ship.

The material on military maritime accidents from Norway and Sweden and the data in Table A4 reflects the five fatalities sustained during these incidents—four in Sweden and one in Norway. In total, there were five military ships lost or abandoned during the period of study between 1990 and 2015. Half of the accidents were collisions, and only one involved fire. Of the 14 incidents, four were the result of activity called for by the military role of the ship (the collision between the HMS Luleå and the HMS Nynäshamn, the collision between combat boats 867 and 929, the grounding of the KNM Oksøy and the shooting accident involving combat boat 863). These four accidents make up four out the five fatalities, but only five of the 38 injured.

4. Analysis and results

4.1 Organization and management

4.1.1 The role of management in susceptibility to accidents and attacks

According to the data, a weapon hit typically leads to fatalities. Therefore, avoiding being hit is an important aspect of survivability. In the Falklands War, for example, the course of events leading up to the attacks described in Cases 1.A and 1.B show that the probability of being hit is affected different actions including vessel maneuvers, adaptive sensor and weapon use (Woodward & Robinson 1992), which is also supported by more general data (Schulte 1994). Therefore, the Falklands War shows that susceptibility management is important and includes system understanding and situational awareness. In the examined material, there are several examples of tactical susceptibility reduction, i.e., when the commanding officers are able to use the ship's systems and capabilities to minimize the probability of a weapon hit or reduce the number of hits for their own ship or for other ships in the fleet. Therefore, in relation to susceptibility, the management task is to avoid being hit. Given the sources here, tactical susceptibility reduction depends on fast decisions based on an in-depth knowledge about the ship in relation to the specific threat and external situation, but also require that the crew is sufficiently trained specifically for these actions and tasks.

The Falklands War also highlights the importance of the organization and management of the fleet (strategy). It is identified that the number and types of incidents are also decided by the UK post-World War II naval strategy employed, which determined the UK's fleet composition and the UK's approach to the conflict. One example is how the UK submarines reduced attacks from the

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Argentinian navy. In war, the ability to combine different types of ships and use them in a coordinated manner is a central safety management factor.

In regard to accidents, military concepts of operation and tasks often introduce specific situations that put the ship at risk (increase susceptibility to accidents), such as an exercise at high speeds without radar as demonstrated by Case 4.A. Some of these situations are unnecessary, i.e., a result of a mistake or create extra value such as driving close to other ships without it being called for (see, for example, Table A4 incidents #7, #8 and #11), if possible, be reduced through safety management. The studied peacetime accidents include several cases of collisions and groundings. The probability of collisions and groundings varies by activity. In particular, groundings and collisions between ships increase if several vessels participate in the same activity and if such activity is performed in congested waters; see, for example, Case 4.A. However, as shown by Case 4.B and 4.C, not all collisions and groundings are the result of activity called for by the military role of the ship.

4.1.2 The role of management in vulnerability to accidents and attacks

Antagonistic attacks in war and peace-time produce the same type of damage, i.e., the same type of survivability needs. However, single hits are more common in situations other than war, and multiple hits and/or several attacks are more common in war. The differences in vulnerability lie in relation to whether vital systems are protected and how redundancy and separations are utilized to make it possible to maintain operability during a subsequent attack. During the Falklands War many of the UK ships lost were lost after multiple hits and subsequent attacks. The state of the ship upon impact is a part of the ship’s vulnerability but is also an important aspect of its recoverability. Therefore, ensuring that the ship and crew are prepared is an important management task (maintenance, training and onboard routines). The management aspect of vulnerability is also the starting point for recoverability. The material shows that being prepared for a weapon hit reduces damage, and the preparations before the hit are important; moreover, effective management requires knowledge about the ship in order to be able to ensure that the preparations and decisions taken are effective.

4.1.3 The role of management in recoverability after accidents and attacks

From the data, it can be identified that in all operational types studied, it is important to have the ability and capacity to mitigate the detrimental effects of injuries, severe structural damage and large-scale fires and flooding. For example, Case 1.B indicated that the ARA General Belgrano was not sufficiently prepared for being attacked or hit. This led to a high number of fatalities as a result of the vessel’s fast sinking.

The material also shows that recoverability management starts long before the attack and needs to include known procedures that ensure that the ship is prepared for an attack and that all on board are sufficiently trained. The preparedness on board and whether the attack was a single attack or a follow-up attack has a large effect on the recoverability. In relation to recoverability it is also shown that critical support is available due to the fact that military ships often operate together.

From the cases during the Falklands War and larger attacks (other than war), it can be seen that the redundancy and separation of onboard systems will not work if management lacks an understanding of how the ship should be prepared. All systems that can be affected by an attack and by accidents can be affected by management decisions and a proficient crew. In the data, there is a large difference between the effects of severe damage and this difference is largely explained by management-introduced preparations. Having high recoverability and thereby reducing the consequences of damage demands ship-specific training and medical competence.

4.2 Personnel

4.2.1 The role of personnel in susceptibility to accidents and attacks

Everyday accidents are typically initiated by a chain of internal factors or issues were also latent organizational issues play a substantial role. These incidents are similar to civilian accidents, and nothing in this study indicates any large difference between everyday military accidents and the various civilian issues described in Section 2.1. Examples include Cases 3.B, 3.C, 4.B and 4.C. However, the severe incidents studied here are initiated during training and exercises, i.e., during an operation where the activity deliberately differs from everyday activity and deliberately stresses the system. Examples include cases 3.A and 4.A. In such situations the preparedness and effective training of the personnel is crucial and there are typically even more complex chain of events and management aspects involved in the incident causation.

4.2.2 The role of personnel in vulnerability to accidents and attacks

External threats during peace and war are a part of the task of the ship, i.e., avoiding the situation may not be an alternative and is out of the specific crew member’s control. Additionally, the crew must be prepared for the fact that in such situations, a large part of the personnel on board will be tired or injured. Therefore, it must be possible for such situations to be managed by a tired crew. Examples include Cases 1.A, 1.B, 2.A and 2.B. These incidents take place during periods of high stress and with tired crews as a result of war or training with the intent to be prepared for war. There are some exceptions, including submarine incidents during normal operations and some of the non-wartime attacks in Table A2. From this, the study identifies that consequences for surface ships during war and training are substantially more significant than consequences as a result of human errors on board. However, on board submarines the higher complexity of systems and the operating environment lead to that a more limited chain of events can have consequences as severe as those encountered during war.

4.2.3 The role of personnel on recoverability after accidents and attacks

Onboard readiness (proficiency in tasks), which ensures that a ship can act according to tactics as well as ensures that recoverability is efficient, is a central safety factor that reduces the consequences of all types of incidents studied. Such readiness does not emerge on its own. The analysis shows that crews are seldom fully prepared for incidents and attacks. It can be hypothesized that more relevant training would decrease the consequences even further. It can also be concluded from the incidents studied that recoverability always involves teamwork, as it is only effective if a large part of the crew work together. This is only possible if the crew is sufficiently trained. Many of the tasks must be performed independently of top ship management, who must be able to focus on prioritizing recoverability efforts and preparing for subsequent attacks.

Also, every crew member’s ability to handle the relevant subsystem according to orders is important. In recoverability, the ability to take individual action based on limited information is crucial. The same is seen for accidents, i.e., the effectiveness of recoverability is governed by every member’s actions being effective despite limited management (which is typically enabled by training).

4.3 Effects of design

4.3.1 Effects of design on susceptibility to accidents and attacks

The performance of technical systems and the readiness is, in the material studied, seen to make a difference in the susceptibility of the ship. The susceptibility options available are defined by the operational technical systems. From the cases during the Falklands war it is seen that there was limited onboard experience with handling the ship systems which affected the susceptibility. Also, Finlan

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(2004) describe that the aircraft carriers and early aircraft warning systems (submarines were used because of a lack of suitable systems) were not designed for the type of warfare fought during the Falklands War. Therefore, the design and state of technical systems affects the probability of a weapon hit, i.e. effect susceptibility. The design of naval ships is especially challenging as a result of the limited knowledge among both designers and crews on the war and attacks a given ship will encounter.

4.3.2 Effects of design on vulnerability and recoverability

The case studies show that technical solutions that limit the effect of damages, such as separation, redundancy and diversity of functions on board, are important for creating conditions for recoverability. The analysis also shows that in peacetime, technical solutions that limit vulnerability are important to minimize the direct consequences of weaponry hits by reducing the damage, the extent of flooding and make sure that onboard systems work despite the damage.

4.4 Quantitative results and fire risk

Based on the findings in described in Sections 4.1-4.3 this sections describes the quantitative analysis with the intent to support a discussion on the generalizability of the findings. Figure 2 shows that the level of societal risk is very dependent to the threat level. However, operational conditions also affect the risk, as illustrated by the large difference in risk level between surface ships and submarines during peacetime as well as by the difference in risk level between UK and Argentinian ships during the Falklands War.

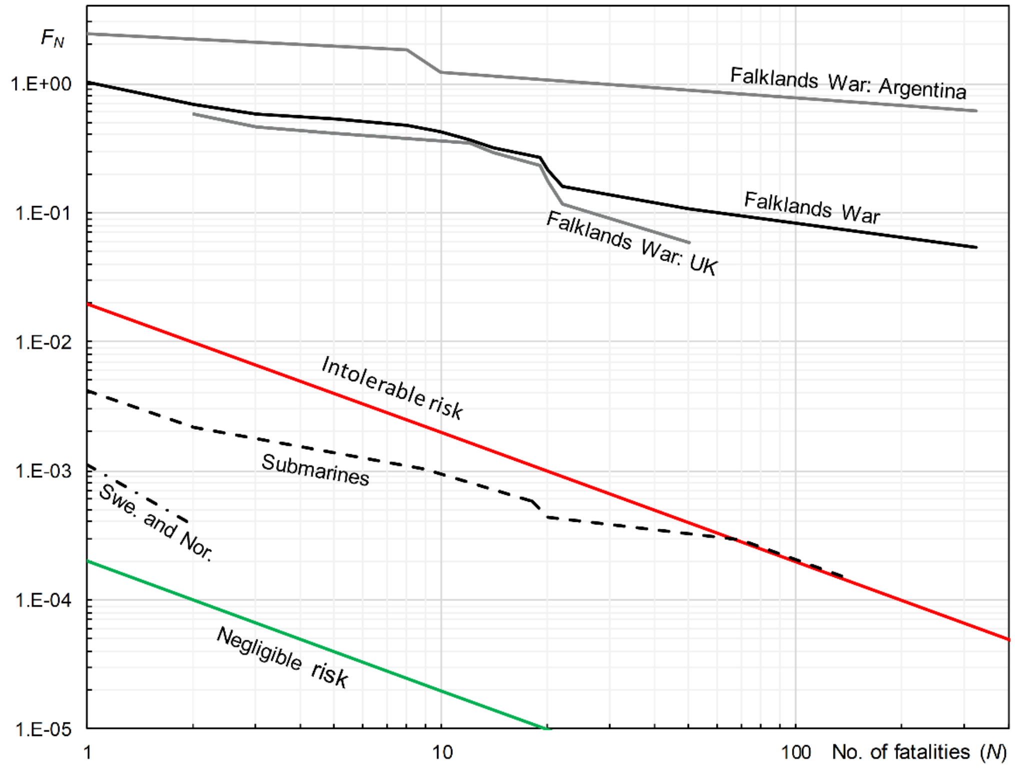

Fig 2 F_N diagram of the fatalities in the Falklands war (solid line), submarine accidents (dashed line) and the Swedish and Norwegian navies' accidents (dashed-dot line). The Intolerable and Negligible limits for peacetime operations are here included as an reference and calculated according to (IMO 2000), with the Swedish Navy as reference (Liwång 2018); given other navies' operational conditions, the limits can both be higher and lower

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From the data in Figure 2, it can be identified that in the Falklands War, the fatalities per ship were substantially higher for Argentina than for the UK. Additionally, by examining the fatalities and the ships lost in Table A1, it can be identified that greater efforts were needed to sink a UK ship than an Argentinian ship, which is also noted in the difference between Cases 1.A and 1.B. The slope of the FN diagram differs between different operation types and between UK and Argentina. A slow decrease for higher fatalities (*N*) indicates that the de-escalation of consequences is challenging. Therefore, according to the investigated cases and the data, de-escalation and limiting secondary consequences are particularly challenging in periods of war and in submarine operations and were especially challenging for Argentina during the Falklands War. This also support the qualitative findings.

In high-risk operations (naval war), fire as a result of weapon hits is a potential risk driver (Høyning & Taby 2000; Liwång 2016) as illustrated by the difference in risk level between the areas for *Peace time military operations fire risk* and *High risk military operations fire risk* in Figure 3. The material studied here allows for analyzing these general statements in regard to fires on board naval vessels in more detail. The estimated risk levels for fire during high-risk operations determined by Liwång (2016) are shown in Figure 3 and are compared to the data collected here.

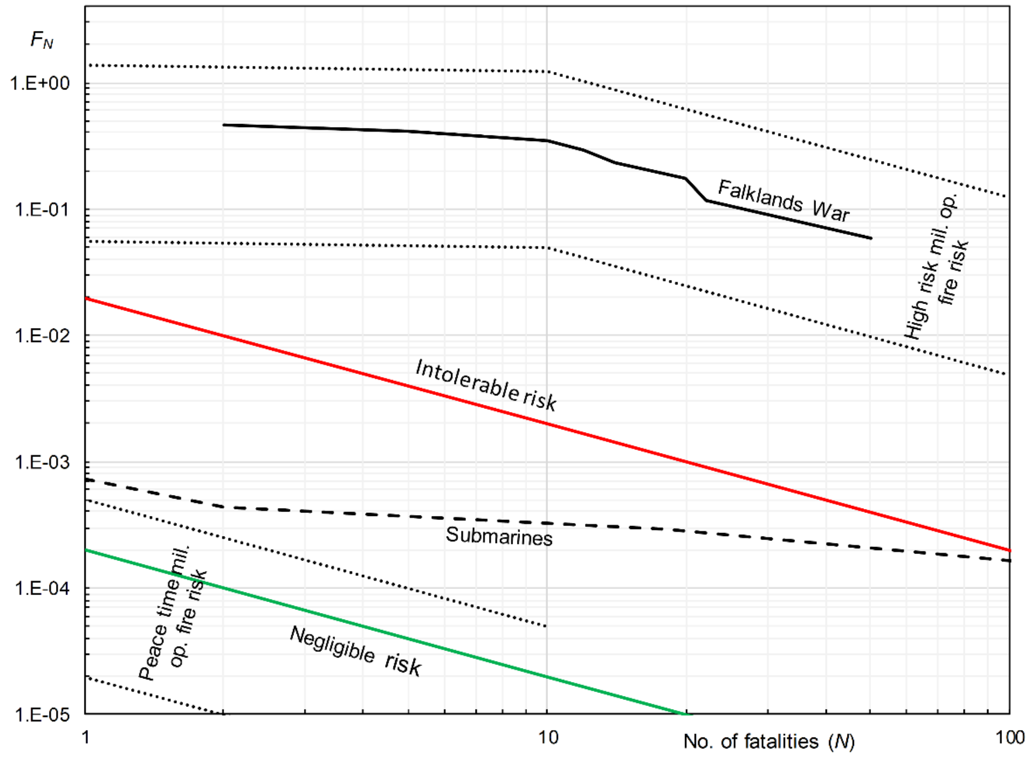

Fig 3 F_N diagram for fire risk during the Falklands War (solid line, data from the incidents described in Table A1), submarine accidents (dashed line, data from the incidents described in Table A3). The fire risk in the material studied here during peacetime operations on surface ships is too small to be assessed based on the data from the incidents in Table A4. Dotted lines: estimated fire risk levels for different types of naval military operations according to Liwång (2016). See Figure 2 for information on the Intolerable and Negligible limits

By comparing Figure 2 and Figure 3, it can be confirmed that the fire risk during naval war is high and makes up a relatively large proportion of the risk in such operations and that the fire risk during peacetime operations for surface ships is most likely negligible. The estimated fire risk level and the slope of the fire risk F_N curve for war operations determined by Liwång (2016) is confirmed to be relevant by the data from the Falklands War. Figure 3 also shows that for peacetime submarine operations, fire risk is high in general and especially high in incidents with a high number of fatalities. This means that de-escalating a fire is a substantial challenge, especially on board submarines.

It can be seen that the fire risk, just like risk in general, on board military ships is very dependent on the operation at hand and the threat level. The analysis of fire risk also highlights how risk drivers (in fire risk, the ignition source) are externally introduced (by the enemy) during war (for example Table A1 #9 and #13) and internally introduced during accidents (for example Table A3 #1, #12 and #16 and Table A4 #5). The probability of a fire is therefore a result of the tactics employed by the ship management during war and antagonistic attacks and a result of the activities and actions on board in accidents.

5. Important safety aspects identified and discussion

The analysis shows that an incident is, given the different types of high-risk activities military vessels perform, not necessarily a result of an internal error or problem, not even a result of a combination of internal causes. Incidents are more typically the result of an external hazard or threat being greater than was expected or prepared for. In the military context an unwanted event is not necessarily an avoidable event or an event with significant consequences. However, the consequences for this externally initiated event can be reduced substantially with training, preparations and suitable chains of actions.

Compared to surface ships, for submarines, there is a thinner line between safe and unsafe operations. This makes the system more sensitive to incidents. Therefore, on board a submarine, a shorter chain of management or maintenance issues alone is enough to cause a serious incident that could lead to multiple fatalities. Subsequently, onboard submarines traditional maritime safety issues and accidents during exercises and training are of greater relative importance because the level of consequences they produce are in the same order of magnitude as wartime attacks. For surface naval vessels, a large number of fatalities is seldom the result of only a single accident.

It is identified that in order to ensure safety after a hit, a continuous management effort is needed. This effort starts long before the operation in question. This was seen in all types of studied incidents. In accidents on surface ships, proactive recoverability management has the potential to limit damage and the lives lost to the direct consequences of the incident. In accidents on board submarines or in incidents with an antagonistic intent, secondary consequences are greatly reduced by proactive recoverability management, but often substantial.

The different operational types (war, submarine operations, and peacetime) have different risk levels but, to some extent, have the same types of safety issues. Risk is high when the ship is not managed in preparation for war. Recoverability, i.e., the ability to limit consequences and especially large scale consequences, was a safety factor (improves safety) in all operational types studied. Therefore, safety work on naval vessels does not need to differ substantially between peacetime and war even though the situations differ substantially.

During peacetime, some accidents are a result of risks introduced by military tasks and exercises; in the material studied, these have more severe consequences compared to other accidents. During wartime, the consequences are dominated by the results of the external threat. The qualitative investigation shows that the probabilities of both training incidents and attacks are affected by management decisions. In peacetime, it is important to avoid situations with unnecessary high risk, and in wartime, it is important to prepare for likely situations through susceptibility management and recoverability management for the specific situation at hand, this calls for a thorough understanding of the strengths and weaknesses of the ship’s systems that are specifically related to the threat and the environment at hand. Therefore, different risk management approaches are needed with different levels of acceptable risk. However, avoiding dangerous training in order to reduce peacetime risks will decrease recoverability in all situations and also decrease war-time susceptibility. In the study it is for example identified that coordinated activities, especially in congested waters, are necessary and a point of strength in military operations because performing coordinated activities is shown to reduce the probability of an attack and the consequences of accidents or attacks.

Political and strategic decisions have a substantial, though indirect, effect on safety on board naval vessels. The organization and coordination of the fleet have large effects on risk levels during war. This effect further stresses the importance of management and coordinated training and exercises during peacetime. Without high-risk peacetime activities, such as submarine operations in general and the operation of several ships together, navies and ships cannot be prepared for war.

The types of severe accidents that occur in peacetime on board submarines worldwide and on surface vessels in Norway and Sweden are relatively similar, and for the accidents studied here approximately 30 percent led to fatalities. However, the average number of fatalities was ten times higher for submarines (the difference is also substantial if the number of fatalities is corrected for crew size). The difference in risk levels is, to a large extent, the result of much more severe consequences that result from the large secondary consequences of accidents on board submarines. In submarines operations the risk is therefore lowered by reducing the frequency of potential initiating events at sea by adapting the work situation even further to the human element or, if possible, by increasing the probability of escape if there is an accident. Neither option is particularly easy. On surface vessels, the peacetime consequences of an accident are most often limited to the direct consequences of the accident itself, and the crews are, if properly trained, generally effective in maintaining control over the situation and limiting any potential subsequent consequences to personnel and the ship.

Military-specific tasks are a challenge during all types of activities, from peacetime exercises and more specialized types of operations, such as submarine operations, to war. Therefore, it is important to plan, prepare, and train for war even though these tasks are challenging and dangerous. The operators must be able to create an explanatory model of cause and effect that managers can use in training and preparations and all on board can use during an incident. The system that must be understood is not limited to the vessel. External threats and hazards must also be included in the understanding of the risk.

This study shows that susceptibility, vulnerability and recoverability should also be treated as functions of management, training and proficiency. All ships have strengths and weaknesses in terms of susceptibility, vulnerability and recoverability. From the studied cases, it is seen that management is about knowing the strengths and weaknesses of the system as a whole and getting all crewmembers involved in increasing proficiency in performing the onboard tasks related to everyday preparedness and during an incident. Typically, the capability of military crews is high, and in many of the studied cases, the consequences are low relative to the severity of the incident and the damage to the ship. In summary, safety management on board naval vessels includes the following:

- Risk management on board needs to be specifically adopted to the hazards and threats relevant for the activity at hand.
- Training and preparedness for an attack is the first step of recoverability.
- Effective management decisions made during an attack have a large effect on susceptibility.
- Training and preparedness for complicated recoverability tasks such as firefighting, flooding control, medical aid and the transportation of the injured is crucial for effective recoverability.

Risk culture, risk taking, susceptibility, vulnerability and recoverability need to be considered. All aspects have an important effect on the consequences and are primarily a function of management decisions in combination with crew preparedness.

This study also shows that, given the possibility of antagonistic threats, safety on board naval vessels cannot be understood by only analyzing safety issues (with negative impact on safety). Safety factors (with positive impact on safety), especially those related to dealing with external threats, must also be analyzed and understood. The absence of ship and operational-specific safety factors, i.e., not using or being able to use what one has, must be considered both systematically and continuously, and these factors have a larger effect on the risk level compared to the effect of typical civilian safety issues. Typically, in the material studied here, the challenges related to applying relevant safety factors relate to management not fully understanding the interaction between social and technical components of the ship in relation to the operation at hand. There are substantial possibilities to develop the science of safety and security in relation to these tensions between internal and external causes of incidents and as a result of the need for preparing for *atypical* situations during *typical* operations. The hope here is that the situations and cases studied and described can be used as a set of cases that, together with other suitable and complementary examples, can assist in making conclusions that will assist future decision makers and increase the understanding needed to tackle safety and survivability issues.

6. Conclusions

Many of the individual actions performed on board the studied ships in war, during and after attacks and after accidents were extraordinary. The studied incidents are typically the result of an external hazard or threat being greater than was expected or prepared for and the consquences of an incident is the combination of several different actions onboard and organizational aspects. Antagonistic attacks are typically an attack from outside the system, and the initiating event is therefore not the result of an action or mistake on board. Internal safety factors that limit the consequences of the initiating event should therefore be a focus. For accidents during peacetime, the civilian safety themes and issues described in literature are also relevant for military ships.

The different operational types (war, submarine operations, and peacetime) have different risk levels but have, to some extent, the same types of safety issues. In general, risk is high when the ship is not prepared and managed for an external attack; the recoverability, i.e., the ability to limit consequences, is a safety factor in all of the operational types studied. However, the relative importance of accidents is larger for submarines because the accidents often create consequences with the same order of magnitudes as attacks. In general the probability of an incident occurring is governed by management decisions, and the effectiveness of recoverability actions is governed by to what extent the crew can take suitable actions despite limited management.

The combination of relatively large crews with extensive training and the fact that the most potent hazards and threats are external leads to a need for management, especially risk management, which differs substantially from the management of civilian ships. A substantial focus must be placed on situations that are, in every aspect, very far from typical operational situations. It must be possible for all important tasks on board to be performed when the performances of the management, crew and technical systems are heavily degraded. This leads to a need for extra levels of system understanding, for management and for personnel. These extra levels are needed in order to create an effective safety understanding that also can meet external threats.

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Appendix A

Table A1. Incidents (hits, i.e., noticeable effect of impact or detonation) involving ships during the Falklands War 1982 (Marsh 1983; Rivas 2012; Schulte 1994; Smith 1989; Woodward & Robinson 1992). If no information or data was found the field is left blank. Ship-to-ship missile (SSM) and Air-to-surface missile (ASM). There were several smaller non-military vessels, but with military tasks, that were captured and recaptured off The Falklands during the war (Rivas 2012). These are not included in the list.

#	Ship	Date	Type	Ship hit	Fatalities	Injured	Ship lost or abandoned
#1	Guerrico	3-Apr	Small arms fire	yes			no
#2	ARA Santa Fe	25-Apr	Air strike	yes	0	1	yes
#3	HMS Arrow	1-May	Air strike	yes	0	1	no
#4	Islas Malvinas	1-May	Air strike	yes	0	0	no
#5	HMS Alacrity	1-May	Air strike	yes	0		no
#6	HMS Arrow	1-May	Air strike	yes	0		no
#7	HMS Glamorgan	1-May	Air strike	yes	0	0	no
#8	ELMA Formosa	1-May	Friendly air strike	yes	0	0	no
#9	ARA General Belgrano	2-May	Torpedo	yes	323	69	yes
#10	Hipolito Bouchard	2-May	Torpedo	yes	0	0	no
#11	HMS Conqueror	2-May	Depth charges	yes	0	0	no
#12	ARA Alferez Sobral	3-May	SSM	yes	9	8	no
#13	HMS Sheffield	4-May	ASM	yes	20	24	yes
#14	Narwhal	9-May	Air strike	yes	1	0	yes
#15	Isla de los Estados	10-May	Naval gun fire	yes	22		yes
#16	HMS Glasgow	12-May	Air strike/bomb	yes	0	1	yes
#17	Rio Carcana	16-May	Bomb	yes	0	0	yes
#18	Bahia Buen Suceso	16-May	Cannon	yes	0	0	yes
#19	Rio Carcana	23-May	ASM	yes			yes
#20	HMS Argonaut	21-May	cannon/rocket	yes	0	3	no
#21	HMS Antrim	21-May	Air strike/Bomb	yes	0	7	no
#22	HMS Broadsword	21-May	Air strike/Bomb	yes	0	14	no
#23	HMS Argonaut	21-May	cannon/rocket	yes	2	0	no
#24	HMS Ardent	21-May	Air strikes	yes	5	10	yes
#25	HMS Brilliant	21-May	Cannon/rocket	yes	0	5	no
#26	HMS Ardent	21-May	Air strikes	yes	22	36	yes
#27	Rio Iguaza	22-May	Air strike	yes			yes
#28	HMS Antelop	23-May	Air strike/bomb	yes	3	9	yes
#29	RFA Sir Galahad	24-May	Air strike/bomb	yes	0	0	no
#30	RFA Sir Lancelot	24-May	Air strike/bomb	yes	0		no
#31	RFA Sir Bedivere	24-May	Air strike/bomb	yes	0		no
#32	HMS Fearless	24-May	Air strike/bomb	yes			no
#33	HMS Broadsword	25-May	Air strike/bomb	yes	0	0	no
#34	HMS Coventry	25-May	Air strike/bomb	yes	19	30	yes
#35	SS Atlantic Conveyor	25-May	ASM	yes	12	1	yes
#36	RFA Sir Galahad	8-June	Air strike/bomb	yes	50	57	yes
#37	RFA Sir Tristram	8-June	Air strike/bomb	yes	2	0	yes
#38	HMS Plymouth	8-June	Air strike/bomb	yes	0	5	no
#39	HMS Glamorgan	12-June	Improvised ASM	yes	14	14	no
Σ					**≥492**	**≥295**	**15**

Table A2. Example of antagonistic attacks in situations other than war 2000-2012 (IMB 2011; King 2013; Langworthy et al. 2004; Republic of Korea 2010; US Department of Defense 2001).

#	Vessel	Year	Type	Ship hit[a]	Fatalities	Injured	Ship in port[b]	Ship lost, abandoned or taken out of service
#1	USS Sullivan	2000	Interrupted IED	no	0	0	yes	no
#2	USS Cole	2000	IED	yes	17	39	yes	no
#3	MV Uhana	2000	IED	yes	8		yes	yes
#4	Dvora patrol craft	2002	IED	yes	0	4	yes	no
#5	Tender, USS Firebolt	2004	IED	yes	0[c]	0[c]	yes	
#6	USS Ashland	2005	Rockets	yes	1	0	yes	no
#7	USS Kearsage	2005	Rockets	yes	1	0	yes	no
#8	Sri Lankan Navy	2006	IED	yes	13			yes
#9	Sri Lankan Navy	2006	IED	yes	18		yes	yes
#10	Dvora patrol craft	2009	IED	yes	0	0	yes	no
#11	Beautemps-Beaupre	2010	Firearms	yes	0		no	no
#12	ROKS Cheonan	2010	Torpedo	yes	46		no	yes
#13	French Navy vessel	2010	Firearms	yes	0	0	no	no
#14	EUNAVFOR vessel	2010	Firearms	yes	0	0	yes	no
#15	US warship	2011	Interrupted IED	no	0	0	no	no
#16	NATO Coalition vessel	2011	Interrupted IED	no	0	0	yes	no
#17	Kenyan Navy vessel	2011	Rockets	yes	0			no
#18	USS Miami	2012	Arson in yard	yes	0		yes	yes
Σ					**≥104**	**≥43**		**≥5**

[a] Hit, attacked or detonation.
[b] In port or close to shore.
[c] Reported fatalities (3 persons) and injured (4 persons) most likely relates to onshore personnel as a result of attacks towards land.

Table A3. Identified submarine incidents 2000-2015 within the world submarine fleet, excluding Iran and North Korea (Associated Press 2006; Australian Maritime Digest 2009; Brannon 2003; Bussert 2003; Chivers & Drewaug 2005; Defense Daily 2003; Dettmer & Harder 2000; Federal Information & News Dispatch 2013; Grace 2012, 2013; IDRW News Network 2015; Interfax 2013a, 2013b; Konetzni 2009; Luther 2006; Mumbai Mirror 2010; Munsey 2002; Munsey & Hegh 2003; Nordenman 2007; Pugliese 2006; Sea Power 2002; Tringham 2012; US Fed News Service 2005a, 2005b, 2007a, 2007b, 2008, 2009, 2010; Wilcock 2011; Willett 2005; Zarakhovich 2003).

#	Vessel	Year	Type	Fatalities	Ship lost, abandoned or taken out of service
#1	Kursk	2000	Explosion	141	yes
#2	USS Greeneville	2001	Collision with surface vessel	0[d]	no
#3	USS Greeneville	2001	Grounding	0	no
#4	USS Greeneville	2002	Collision	0	no
#5	USS Dolphin	2002	Fire and flooding	0	no
#6	Oklahoma City	2002	Collision	0	no
#7	HMS Trafalgar	2002	Grounding	0	no
#8	HMAS Dechaineux	2003	Flooding	0	no
#9	Ming 361	2003	Accident	70	yes
#10	K-159	2003	Sinking/Flooding	9	yes
#11	USS Hartford	2003	Grounding	0	no
#12	HMCS Chicoutimi	2004	Fire	1	no
#13	USS San Francisco	2005	Grounding	1	no
#14	AS-28	2005	Stuck to bottom	0	no
#15	USS Philadelphia	2005	Collision	0	no
#16	Daniil Moskovsky	2006	Fire	2	no
#17	USS Minneapolis-St Paul	2006	Crew overboard	2	no
#18	USS Newport News	2007	Collision	0	no
#19	USS Hartford	2007	Collision	0	no
#20	HMS Tireless	2007	Gas accident	0	no
#21	HMS Superb	2008	Grounding	0	no
#22	K-152 Nerpa	2008	Gas leak	20	no
#23	Triomphant	2009	Collision (UW)[e]	0	no
#24	HMS Vanguard	2009	Collision (UW)[e]	0	no
#25	USS Hartford	2009	Collision	0	no
#26	INS Sindhurakshak	2010	Fire	1	no
#27	INS Shankush	2010	Crew overboard	1	no
#28	HMS Astute	2010	Grounding	0	no
#29	HMCS Corner Brook	2011	Grounding	0	no
#30	USS Miami	2012	Arson in dock	0	yes
#31	USS Montpelier	2012	Collision	0	no
#32	INS Shankush	2012	Fire	0	no
#33	INS Sindhurakshak	2013	Explosion and sinking	18	yes
#34	K-150 Tomsk	2013	Fire	0	no
#35	USS Jacksonville	2013	Collision	0	no
Σ				**266**	**5**

[d] 9 fatalities on board the surface vessel.

[e] Triomphant and HMS Vanguard collided with each other.

Table A4. Reported severe Swedish and Norwegian accidents 1990-2015 (Ekanger 2014; NTB 2006; Swedish Accident Investigation Authority 1992, 2000, 2004, 2006, 2008, 2016; Swedish Armed Forces 2008, 2010). The Swedish accidents (#1, #2, #4, #6-8, #10-14) are analyzed in more detail in Liwång (2018).

#	Vessel	Year	Type	Fatalities	Injured	Ship lost, abandoned or taken out of service
#1	HMS Luleå, Swe	1991	Collision with HMS Nynäshamn	1	0	no
#2	HMS Nynäshamn, Swe	1991	Collision with HMS Luleå	0	0	no
#3	KNM Oslo, Nor	1994	Grounding	1	10	yes
#4	Combat boat 820, Swe	1999	Collision with land	0	7	no
#5	KNM Orkla, Nor	2002	Fire	0	4	yes
#6	Combat boat 881, Swe	2003	Collision with land	0	0	yes
#7	Combat boat 867, Swe	2004	Collision with Combat boat 929	2	0	no
#8	Combat boat 929, Swe	2004	Collision with Combat boat 867	0	0	no
#9	KNM Oksøy, Nor	2004	Grounding	0	5	no
#10	Combat boat 848, Swe	2006	Loss of watertight integrity	0	8	yes
#11	Combat boat 863, Swe	2008	Shooting accident	1	0	no
#12	HMS Malmö, Swe	2008	Green water incident	0	0	no
#13	Combat boat 831, Swe	2009	Green water incident	0	0	no
#14	G-boat 091, Swe	2014	Collision with buoy	0	4	yes
Σ				**5**	**38**	**5**