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Minimising Risk from Armed Attacks: The Effects of the Nato Naval Ship Code

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Abstract

The NATO Standardization Agency (NSA) is proposing a Naval Ship Code (NSC) that can be applied to surface naval vessels and other vessels operated by the armed forces or agencies of a state. The NSC is optional and based on, and benchmarked against, conventions and resolutions of the International Maritime Organisation.

The NSC cover areas such as ship controllability, engineering systems, fire safety, evacuation, communications and navigation. The code does not include measures specifically designed to address the effects of armed attack.

The covered areas in NSC are however also very important when the effects from armed attack is to be minimised. This work investigates how the NSC will effect, and interact with, measures to ensure survivability under attack. Survivability is here seen as a function of the ships susceptibility, vulnerability and recoverability. Based on two case studies this paper exemplifies the effect of the NSC on the vessels total safety. The case studies presented are

ballistic protection on smaller naval vessels and bridge configuration to minimize effects of attacks.

Introduction

As stated in the Maritime Strategy of the United States of America (DoD, 2007) the economy of the world is tightly interconnected and 90% of the world trade are transported by sea. The sea-lanes and supporting shore infrastructure are therefore very important to the global economy. The conflicts of today are increasingly characterized by a blend of traditional and irregular tactics, decentralized planning and execution, and non-state actors using both simple and sophisticated technologies in innovative ways. Naval operations of today are more focused on the littoral and the number mission types as well as threats are increasing (NSA, 2010). The Maritime Strategy therefore conclude that these conditions combine to create an uncertain future and sets also new demands on naval security as well as on naval ships to counter these threats. The need for further development of maritime security is also recognised by non-military authorities such as the International Maritime Organisations (IMO) and the European Union. In the wake of the terrorist events September 11, 2001, new civilian maritime regulations, such as the International Ship and Port Facilities Security Code (ISPS Code/IMO, 2002a) has been developed and implemented (Hesse, 2003).

Total safety or security can never be achieved (Grimvall, 2003:11 and Hughes, 2000:361) and safety, as well as security, efforts focus on reducing risk. How risk is assessed is therefore crucial when designing analysis methods, this especially as measures to reduce risk often are interconnected with each other and not possible to change without affecting other safety or security areas. It is a matter of compromises. How to systematically enhance survivability is an important question for both defence executives involved in technology development and field commanders in tactical deployment.

Aim and method of study

The aim of this study is to investigate and describe the effects of the Naval Ship Code (NSC) on efforts to enhance ship survivability. The study is a qualitative case study with two cases: ballistic protection on smaller naval vessels and bridge configuration to minimize effects of attacks. The two cases are based on documentation of typical solutions for Naval Ships. The two cases are chosen so that they will cover a range of requirements types. In these two areas the regulations, id est the aims, goals, functional areas, performance requirements and verifications methods, of the NSC will be compared to survivability measures. The result will be discussed in respect to how the NSC affects the total safety efforts.

Safety

Reason (2000) defines safety as the *'ability of individuals or organisations to deal with risks and hazards so as to avoid damage or losses yet still achieve their goals'*. Reason also describes that effective safety work needs informed participants that can navigate close to unacceptable danger without passing over the edge.

Reason concludes that especially in areas with few but severe incidents it is hard to develop safety work and measure safety by negative outcomes. It is also important not to infuse a false sense of security so that the operators not know to be afraid. The human ability to adjust to changing events is what preserves system safety in a dynamic world and to constrain operator's variability is therefore undermining one of the most important safeguards. A successful culture knows that hazards will not go away, *'they anticipate the worst and equip themselves to cope with it'* (Reason, 2000).

According to Parker et al (2005) a desirable safety culture does not just emerge, it is a result of many aspects. As a part of the work Parker et al describes 18 organisational, concrete as well as abstract, key aspects of safety culture. These 18 aspects of safety culture are here summarised to define three, two concrete and one abstract, basic areas of safety culture:

a. Formal regulations and processes including for example methods for benchmarking, audit systems, and risk analysis

b. Competence and training including work quality and safety observations

c. Shared risk awareness throughout the organisation

Maritime safety

Maritime safety regulations developed by the IMO are designed to make sure that passengers, values, crew, surrounding ships and environment is kept as safe as possible. Traditionally the codes were prescriptive to their nature which means that the codes prescribe aspects of design or construction with engineering specifications. Prescriptive standards are generally formulated as a result of accidents and suitable for routine activities but devolve responsibility and innovation and are unsuitable for new developments (Kuo, 2007:27–28). The IMO Code of safety for High-Speed Craft (HSC Code/IMO, 1994) states that for traditional ships it is possible use a prescriptive code and ensure a suitable low risk level. However, for novel or specialised types of ship a prescriptive safety code is too restrictive and a probabilistic method where the risk for different incidents are kept acceptably low need to be used (IMO, 1994: Annex 3). Such a probabilistic code uses a series of standardized expressions to evaluate events and where those with minor effect is allowed to have a higher acceptable probability than a event with hazardous effect. The probability assessment in the HSC Code is based on the operational life of the particular craft, or crafts of the same type. Numerical values of probabilities should be on a per hour or per journey basis.

It is the role of the ships flag state to exercise its jurisdiction and control the ship in administrative, technical and social matters to ensure safety at sea. IMO permit the flag administration to delegate the inspection and survey of ships to a recognised organization that demonstrate technical competence and are governed by the principles of ethical behaviour (Simpson, 2010). There are several classification societies that are recognised by the IMO as recognised organisations and a number of those have rules for classification of naval ships (Simpson, 2010 and DNV, 2009).

The IMO ISPS Code is, as mentioned, a result of the security situation of today and deals with civilian aspects of maritime security. The code is based on the assumption that security of ships and ports is a risk management activity and that, to determine what measures are appropriate, an assessment of the risks must be made in each particular case. The purpose of the code is to provide a standardised, consistent framework for evaluating this risk. The code defines roles, plans and procedures for ship owners and port facilities as a base for secure interaction between ships and ship and port.

Ship survivability

The safety for ships under attack is a question for the state in question and should not be governed by international regulations. Naval combatant ships are excluded from IMO conventions. SOLAS cited from NSA (2010) states that '*the present regulations, unless expressly provided otherwise, do not apply to ... ships of war and troopships*' (NSA, 2010: A-3-3). However, a naval ship usually operates under non-military conditions and the civilian maritime safety regulations are in those conditions often applicable for many parts of the ship (James, 2010). But in some situations, or operations, the conditions make civilian regulations inadequate (Simpson, 2010). This because military success cannot be achieved at sea without great risks (Hughes, 2000) and risk awareness for those situations cannot be dependent only on methods for civilian maritime safety. This means that safety culture and naval operations cannot be discussed without looking at doctrines, this because doctrines are the basis for decisions during an operation (Hughes, 2000). Safety and security efforts are therefore futile without doctrine support and for example technology and manning must be designed with the doctrine in mind and staff involved in design must have doctrines available in order to make and understand the basis for safety related decisions (NSA, 2010:A-3-2). If this is not the case the adopted safety and security solutions may not support the ships concept of operation.

How to define measures of performance and force effectiveness is also a matter of state and governed by doctrines. It is here assumed that the main mission for the naval ship studied here is to maintain control of a given operational area and prevent, and if necessary, stop attacks to the ship itself. The measure of success is therefore survivability – that is, the possibility to safe guard the area and minimizes damage to the own ship. This definition is close to others used in evaluation of naval effectiveness, see for example Perry et al (2002). Note that survivability here means that ship, after the attack, floats, as well as is able to continue its operation. A quantitative measure could then be time operational in the operational area divided by total time elapsed (Effectiveness), or time out of service (seconds or months) per attack (Vulnerability); see equation 1 (effectiveness) and 2 (vulnerability).

$$E=\frac{t_{operational}}{t_{total}} \qquad \text{eqn. 1}$$

$$V=\frac{t_{out\ of\ service}}{n_{attacks}} \qquad \text{eqn. 2}$$

The quantitative measure to chose depends on how the mission is defined and what should be measured. A quantitative study could give insight to mechanism linking a specific type of attack to the survivability for a specific type of ship. An insight very much needed as survivability in the general case is not only a question of having the right weapon systems or soft kill system, it can, as the NSC (NSA, 2010) defines, be described in terms of the susceptibility, vulnerability, and recoverability of the system. Susceptibility describes how easily the ship can be detected including tactical measures. Vulnerability is the inherent ability of the sip to resist damage. Recoverability is the ability of the ship and its crew to sustain operational capability. All three aspects are a function of technology, tactics and efforts done onboard. Survivability can also be described and analysed by layers of protection, the Survivability Onion, see Figure 1 on the next page (Guzie, 2004:11).

Different layers have different characteristics dependent on the type of vessel or vehicle in question. For example can the layer *Withstand hit* for a ship contain ballistic protection, manning as well as fire fighting capability, but for a

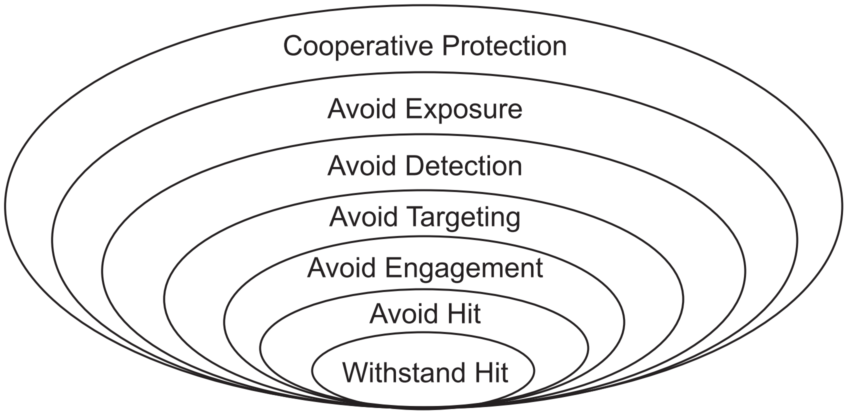

Figure 1. The Survivability Onion, re-drawn from Guzie (2004: 11)

vehicle be more limited to ballistic protection. Most layers also are constituted by a number of aspects and some aspects have impact on two or more layers. For example are the layers *Avoid Detection* and *Avoid Targeting* both dependent on signature management and can therefore be a function of optical, radar, IR, magnetic, acoustic, pressure and electric signatures as well as emitted signals and the hulls wake (Liwång et al, 2001).

There are existing methods for some layers, or parts of layers. For example probability based optimisation of watertight compartmentation for naval ships to increase the ships ability to *withstand hit* (Papanikolaou and Boulougouris, 2004) and models of surface to surface missiles counter measures to *avoid hit* (Birgersson, 2000).

As shown above the survivability is dependent on technology as well as on tactics and manning. To perform an objective study on the different aspects of survivability is therefore complex and a measure of comparative effectiveness is needed. This will then give the possibility to make an objective and quantitative comparison between measures with no obvious common unit of measure (Morse and Kimball, 1998:48). A well defined measure of effectiveness could therefore, in theory, be the link between different evaluation methods and constitute a basis for a design decision support system, see Figure 2.

Case Description

The threats against modern naval ships has become more complex and covers everything from a traditional sea battle to small arms attacks from terrorists and criminals (Westin, 2009 and NSA, 2010:A-3-2). Different kinds of threats

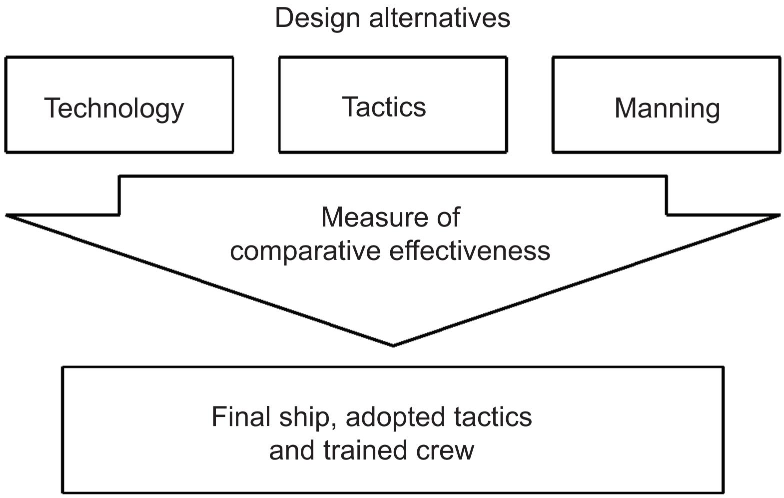

Figure 2. Measure of comparative effectiveness to support decisions of design, construction and operation

demands different kinds of countermeasures and the accepted risks can differ. The two cases will both be based on small arms attacks, but the tactical situation for the attack will not be discuss. The ship discussed is a generic littoral surface combatant with a displacement of 1 200 tons. It is a traditional built monohull with a steel hull and aluminium superstructure. The ship is designed, built and equipped to handle naval warfare and the main defensive protection capability is therefore a combination of soft and hard kill systems as counter measures for surface to surface missiles.

Case 1; supplementary ballistic protection

The first case is the question of retrofitting the ship with supplementary protection to get a basic protection against small arms projectiles, calibre up to 20 mm, fired at close range. The aim of such a protection is to give the possibility to handle new threats that come with new tasks in littoral operations. A suitable level of survivability for this case would be to enhance the protection so that the ship can withstand a short period of hostile fire without high risk of losing any main functions and that the damage can be repaired temporarily with on board repair capability.

The penetration depth for armour piercing 7.62x51mm ammunition is up to 37 mm in steal, see table 1 on the next page.

Table 1. Calculated penetration depth (Westin, 2009)

Ammunition	Hull material	Penetration depth [mm]	
		@ firing range 0m	@ firing range 600m
M993 7.62x51mm AP	steel	37	9
M993 7.62x51mm AP	aluminium	62	15
NM173 12.7x99mm NATO AP-S	steel	77	19
NM173 12.7x99mm NATO AP-S	aluminium	129	32

A typical hull steel plate thickness for a ship this size is up to 15 mm if no account is taken to ballistic protection (DNV, 2009: Part 3 Chapter 2). This means that the ammunition covered in the table above poses a potential threat if no survivability measures are taken.

Westin (2009) showed that it is technically possible to increase the ballistic protection in a few prioritised areas and that the supplementary protection solutions should be designed in a way that admits an easy reconfiguration in order to meet the present threat-level. The limitations in weight and volume also demands for changes in the personnel's movement and usage of areas when under threat to minimise the weight added. However, the extra ballistic protection will affect the possibility to service and maintain on board systems, this because supplementary protection must be used around critical systems as engine room, communications systems and the bridge. In complement to this, personnel need to use body armour and important systems need to be moved to areas of the ship that can be protected.

Case 2; bridge design for small arms protection

The second case is the question of configuring and designing the bridge of the ship and its systems so the risks from small arms attacks are minimised. A suitable level of survivability for this case would be that the ship after a short period of hostile fire to the bridge still can manoeuvre and protect itself.

In contrast to civilian ships, naval ships are often equipped with more spaces than the bridge and engine control room dedicated to command and control of the ship. This means that the bridge on a naval ship is not necessarily the main command place for the operation of the ship. The key issue for the work on a bridge of a civilian ship is safe navigation and the development of technology related to the ship bridge has been rapid during the last decades (Nilsson, 2007:1). On naval ships more information needs to be collected and processed during operation by the crew in comparison to civilian ships. For example needs the radar image to be analyzed for both navigational issues as well as threat assessment (Wikingsson, 2009).

The attributes that make the bridge effective, such as central and high position, 360 degrees view, and that it is recognised as the place of command, also makes the bridge an easy, and often less protected target, at close range attacks. For naval ships where these kinds of attacks are plausible it is therefore important to minimize the number of functions performed on the bridge and adopt technology and crew organisation that supports this goal. This so the bridge configuration and design can be optimised with as few constraints as possible and allow for protection of both personnel and systems. To enhance safety for a naval bridge the regulations must therefore allow the bridge to be designed with the naval ships possibilities in mind and take full use of the other, more easily protected, command and control spaces available. The regulations must also allow the ship to be equipped with systems for a secondary less equipped space for navigation to be used when the bridge is deemed unsafe or destroyed by an attack.

The Naval Ship Code

The NSC (NSA, 2010) is a new naval code that can be applied to surface naval vessels and other vessels operated by the armed forces or agencies of a state. The NSC is optional and based on, and benchmarked against, IMO conventions and resolutions. The code does not include measures specifically designed to address the effects of military attack. The NSC is goal based and the ship should be verified against the goals during design and construction stages as well as during operation. The goal based approach has according to the code *'several advantages over more traditional prescriptive standards'*:

a. The Naval Ship Code can become prescriptive if appropriate for the subject, or alternatively, remain at a high level with reference to other standards and their assurance processes.
b. The goal based approach permits innovation by allowing alternative arrangements to be justified as complying with the higher level requirements.
c. Non-compliances can be managed in a more controlled manner by referring to the higher level intent. (NSA, 2010:XV)

Six tiers are defined in the code with an increasing level of detail, see Figure 3 on the next page. *Tier 0 Aim*, states the overall objectives of the code. *Tier 1 Goal*, establishes a goal for each safety area (chapter), e.g. Structure and Fire Safety. *Tier 2 Functional areas* defines the areas of special interest for each safety area. *Tier 3 Performance Requirements* should be independent of technical or operational solutions and have a qualitative character that is to be complied

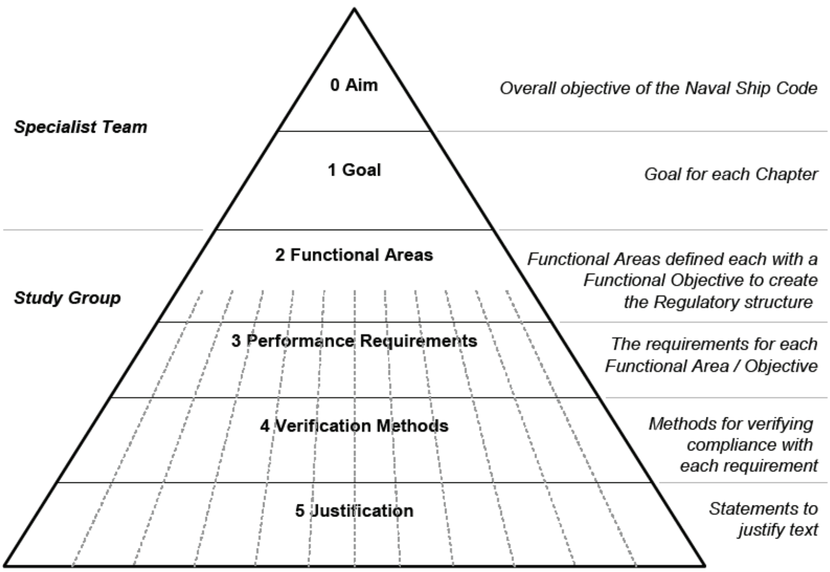

Figure 3. The Naval Ship Codes Six tiers with increasing level of detail

with. *Tier 4 Verification method* is to be defined in one of three ways: prescriptive requirements, a performance based solution or through delegation to a recognised organisation for confirmation. *Tier 5 Justification* is constituted by statements justifying how Performance Requirements are met.

The overall objectives as stated in Tier 0 are that:

1 Through the effective assurance that essential safety functions will be available, the Naval Ship Code provides a framework for the design, construction and maintenance of naval ships with the intention of:

1.1 Safeguarding life in all foreseeable operating conditions throughout the lifetime of the ship;

1.2 Offering a level of safety to which embarked persons are exposed that is no less than the level of safety to which persons embarked on a merchant ship are exposed.

2 For hazards occurring under extreme threat conditions, the code permits an appropriate level of safety as determined by the Naval Administration. (NSA, 2010:I-1)

The NSC cover the areas Structure, Buoyancy, Stability and Controllability, Engineering Systems, Fire Safety, Escape, evacuation and Rescue, Radiocommunications, Navigation and Seamanship, and Dangerous Cargos. All the mentioned areas also play a big role in the ships survivability. Even though the code does not include measures to address hostile attacks the Annex A *'Guide to the Naval Ship Code'* describes how required survivability should be defined as a result of the specific operation profile of the ship. The annex states that potential damage caused by hostiles acts, required post-damage ship capability as well as philosophy for recovery from the damage state must be defined for effective application of the code. This should be defined as scenarios in the ships Concept of Operation (NSA, 2010:IA) and the code also states that policies and doctrines should be made available so that staff involved in design as well as operation can understand the basis for decisions (NSA, 2010:A-3-2).

Based on *3. Case description* there will below be given an overview of the NSC goals, functional areas, performance requirements and verification methods that can interact with efforts to increase ballistic protection. The two functional areas *Structure* and *Escape*, *Evacuation and Rescue* will be described to serve as an example for how the code interacts with efforts to increase protection as described in case 1. The functional area *Navigation and seamanship* will be used for the analysis of case 2.

Regulations effecting case 1, supplementary ballistic protection

According to the NSC the goal for the **structure** is to provide weathertight and watertight integrity, carry loads and protect embarked persons at least until the persons have reached safety. This is to be met throughout the life of the ship. Compliance with the regulations relies upon selecting and implementing an appropriate standard. As stated earlier there are several classification societies that have specific rules for naval ships. Det Norske Veritas (DNV) Rules for Classification of High Speed, Light Craft and Naval Surface Craft (DNV, 2009) will here use the as an example of such a rule. The rules allow for the structure of the ship to be assessed by two main methods; prescriptive regulations and direct calculations. The rules also define basic parameters and method of analysis regarding the physical effect of weapons effect in Part 6 Chapter 18 Combat Survivability. The defined parameters and method should be used to analyse system redundancy for damage extent set by the owner. The probability concept can be used to support the Failure Mode and Effect Analysis (FMEA).

The arrangements for the **escape, evacuation and rescue** of embarked persons shall provide effective escape from all manned spaces to a place of safety. The safety area has functional areas such as *Escape and Evacuation Analysis and Demonstration*, *Inspection and Maintenance*, *Training and Drills* and *Muster Station*. Most of the areas can be verified by testing or demonstration.

Regulations affecting case 2, bridge design for small arms protection

The functional objective for **Navigation** states that the ship shall have adequate arrangements for safety of navigation with the functional requirement that the arrangements are according to the IMO Safety of Life at Sea (SOLAS) convention and Convention on the International Regulations for Preventing Collisions at Sea (COLREGs). Alternative arrangements are permitted where necessary or appropriate to the ships role as defined in the Concept of Operation Concept (NSA, 2010:IX-1).

Result of the analysis

The form of NSC regulations as described above was compared to the types of measures called for in the two cases. This in order to see how the code interacts with measures to increase the ships survivability. The three basic areas of safety culture defined in *2. Safety*; (a) formal regulations and processes, (b) competence and training and (c) shared risk awareness though out the organisation, was used to structure analysis and the results presented below. The first area, formal regulations was analysed for each case separately and the two following areas was analysed for the two cases together.

(a) Formal regulations and processes affecting supplementary ballistic protection in the NSC are not contradicting the effort to increase combat survivability. Both the NSC and DNV Rules for classification promote survivability analysis. However, applying the regulations in practice will lead to situations where results from a survivability analysis must interact with NSC, for example:

- can the supplementary ballistic protection be considered as a part of the ship and thus give a contribution to the ship strength in the direct calculations?
- how can probability be introduced to the High speed, light craft and naval surface craft rules' combat survivability analysis?
- if comparing results from a probabilistic FMEA and survivability calculations according to the NSC annex A and defined scenarios, on what ground can values of probability be compared?
- how should the term *escape to place of safety* be interpreted if the scenarios in the Concept of operation defines the ship as the only safe place, can it change arrangements for escape and evacuation?
- how should *manned spaces* be interpreted given the knowledge that survivability reduces the personnel movements during operation?

If the questions above can be answered before the using the NCS the results from survivability analysis can more effectively be implemented in the design.

(a) Formal regulations and processes in the case of bridge design are prescriptive to their nature and not designed to handle the specific characteristics of a bridge on a naval ship. Alternative arrangements are permitted where necessary or appropriate based on the Concept of operation. The interpretation and implementation of this possibility give rise to a couple of questions that has to be answered in order to facilitate the possibilities introduced by a goal based code:

- how should the Concept of operation be defined in order to be able to support alternative bridge arrangements that not comply with the IMO regulations?
- if compromises are need, how are operations performed under military conditions defined and compared to operation under civilian conditions?

(b) Competence and training and **(c) shared risk awareness though out the organisation** is not specifically mentioned in the NSC except in annex A appendix 3 Naval ship characteristics were the code states that policies and doctrines should be made available to staff involved. This reduces the possibility to reach the important goal of having informed participants and creating a safety culture that can give lasting effects. The cornerstone for naval thinking and acting is the doctrine. From the doctrine the state in question need to extract a Concept of operation for the ship valid for design, construction as well as operation. Defining the Concept of operation and the analysis of events that lead to major degradation of safety are left out from the NSC and in to the hands of the Naval Administration to handle. These events can in the general case be classified as unlikely, but at the same time be very likely to happen for a specific ship when it is set to perform the task it is designed to handle. How the Concept of operation should be described and quantified is central for how the survivability can be implemented and optimised. This is especially challenging as neither the NSC nor the rules for classification gives the theoretical base for how survivability analysis results are to be compared to the results of codes based on empirical data derived from civilian shipping. This makes it hard to give the participants in the process, for example engineers and crew, an understanding on how total safety, including both safety as well as survivability, is achieved and maintained in different situations.

Conclusions and discussion

In *2. Safety* it is concluded that an effective safety work is not only a question of having adequate regulations, but also competence, training and shared risk awareness are also needed. As the NSC does not include measures specifically designed to address military attack it can not in itself be the basis for such an approach. However, the NSC is the only code designed specifically for naval ships and it is therefore more a question on *how* it should be applied rather than *if* it should be applied.

The IMO codes focus on safety, but there are exceptions such as the International Ship and Port Facilities Security Code (IMO, 2002a). The ISPS regulates however mostly planned interactions between ships and between ship and port, the code is transportation hub focused and prescriptive regarding roles and documents onboard and in ports. The code does not give any insight to how the survivability of the ship should be analysed.

The goal based approach of the NSC permits in theory alternative arrangements, but the choice of verification method often reduces that freedom substantially. It is therefore very important to choose a verification method that is suitable for the type of ship and Concept of operation in question.

Both the NSC and the classification rules studied here promote survivability, but it is not defined how the results should be interacting with the NSC goals and Performance Requirements.

The NSC specifies that scenarios in the ships Concept of operation should be used as a base for survivability analysis and the High speed, light craft and naval surface craft rules describes some basis for how weapons effect should be physically analysed.

A systematically survivability work with measure of effectiveness common with used safety rules and codes would serve as very important decision support system during design and operation. This because a naval survivability of the ship is closely linked to its effectiveness and as survivability efforts cannot be fully separated from safety efforts. The two cases studied shows that the NSC does not give any insight to how a quantitative analysis of the ships survivability can be compared to for example a probabilistic analysis according to the classification rules. The NSC defines that survivability should be analysed using defined scenarios in the ships Concept of operation (NSA, 2010:IA-4). The High speed, light craft and naval surface craft rules describes that the probability concept with probabilities based on the operational life of the particular craft can be used in the Failure mode and effect analysis (FMEA). It is easily argued that a FMEA of a naval ship should include events that follow from an armed attack so that redundancy is not only based on safety measures derived from civilian shipping scenarios. However, this is not possible without a common base for probabilities and the NSC does not specify that probabilities should be defined for the scenarios in the Concept of operation. This means that defining a method for assessing probabilities to armed attack and the consequence is needed in order enable an integrated survivability and safety analysis for naval ships.

There are existing safety and security analysis tools that may serve as a baseline also for assessing a probability based survivability analysis. Such tools are for example:

- Formal Safety Assessment (FSA) defined by IMO, the method includes identification of hazards, risk analysis and risk control options (IMO, 2002b),
- Bayesian networks which has been applied in other areas of maritime operations and is focusing on causal relationships and easily understood by involved parties (Friis-Hansen, 2000),
- Integrated Survivability Assessment, a system engineering approach developed for army vehicles (Guzie, 2004), and
- other generic risk analysis methods including methods for analysing antagonistic threats.

These existing tools need to be scientifically evaluated and further research is needed to see how these methods could be used or combined to create a analysis method for naval ship survivability. Such a method should take use of existing methods to model specific layers, or parts of layers, in the survivability onion.

If it is possible to define a probability based method for evaluating ships survivability this could then be used as a tool for:

- assessing probabilities for survivability to be compared to results from the NSC,
- evaluating the ships effectiveness, and
- discussing naval ship effectiveness and survivability with involved parties.

This will then give the possibility to make an objective and quantitative comparison between survivability measures with no obvious common unit of measure, a comparative effectiveness.

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