Enhancing Navigator Competence by Demonstrating Maritime Cyber Security

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As technology continues to develop, information and communication technology and operational technology on board ships are increasingly being networked, and more frequently connected to the Internet. The introduction of cyber systems changes the work environment with the aim of decreasing the workload for the navigator, but at the same time introduces more complexity and vulnerabilities that in turn may alter the competencies needed to perform safe and efficient navigation. The need for contemporary examples of how cyber-attacks can distort situational awareness and interfere with operations are needed to enhance the navigator's competence through increased system awareness. This paper demonstrates some of the possible attack vectors that a cyber-attack can present to a ship, as well as discussing the plausibility and consequences of such attacks. In this study we provide a practical example to better understand how one can demystify cyber for the navigator in order to enhance the navigators` competence.

KEYWORDS

1. Maritime 2. Cyber Security 3. Human Factor 4. Navigation

1. INTRODUCTION

"For the first time in maritime history the positive correlation between capital spent and power is undermined, cyber-attacks are low cost alternatives to physical attacks which have the ability to cripple maritime operations." (Fitton et al., 2015, p. 14). This statement summarizes the current dilemma for the maritime domain, as it is beginning to experience the vulnerable side of reliance on information and communications technology (ICT). The craftsmanship of maritime operations has always been the ability to navigate safely and efficiently the oceans, traditionally performed more or less in isolation from the rest of the world (Fitton et.al 2015). With increased digitization and advances in electronically aided navigation where systems are increasingly being networked and integrated, such as Electronic Chart Displays and Information System (ECDIS), Radar, Automatic Identification System (AIS) and the Autopilot (AP), the maritime domain is increasingly dependent on cyber systems for safe and efficient navigation. However, digitalization and convergence of ICT and operations technology (OT) (BIMCO et al., 2017), creates potential attack vectors for an adversary with intent, persistence and resources to interfere with maritime operations. The current drive towards even more integration of sensors together with increased used of automation to enable for example remote monitored or remote-controlled operations, will potentially bolster the significance of such successful attacks in the near future. Over-reliance in some parts of the integrated navigation system can result in dangerous situations (Norris, 2010, MAIB, 2014), and not being prepared

for a cyber-incident against navigation systems might lead to significant consequences (Gard, 2016). Scholars and industry jointly calls for more cyber security testing of maritime cyber systems, in order to raise awareness and identify the need to conduct appropriate training and education for personnel operating such systems (Fitton et al., 2015, Dyryavyy, 2014). Simultaneously suggesting that to mitigate both the threat of, and potential negative effects of successful cyber-attacks requires investment in both technology and people (Fitton et al., 2015). Despite recent headlines in the media regarding the effects of cyber-attacks in the maritime domain (Baraniuk, 2017, Demchak et al., 2017), there seems to be a lack of relevant examples demonstrating attack vectors and effects of cyber incidents on maritime navigation systems. We argue that more examples of cyber-attack possibilities are needed to aid the conceptual development and understanding of Maritime Cyber Security (MCS).

This article will first explore the contemporary understanding of the emerging concept of MCS. We argue that the current awareness and understanding of cyber security in the maritime domain is insufficient. By using the concept of situational awareness (SA) as a measure of safe and efficient navigation, section 2 and 3 discuss how cyber systems makes SA more complex for the modern navigator. Section 4 introduces a demonstration of MCS carried out for learning purposes at the Royal Norwegian Naval Academy. The main body of the experiment is demonstrating how a cyber-attack can be performed against a modern maritime navigation system. This section also includes the study design and data collection, both utilizing the cyber kill chain model (Hutchins et al., 2011). Section 5 presents the findings from the experiment. Section 6 and 7 discuss impact and conclude the article.

2. Maritime Cyber Security

2.1 The emerging concept of MCS

MCS is a combination of the two terms 'maritime security' and 'cyber security'. The first term; maritime security, has been argued to have no definite meaning, and subsequently relates to different concepts depending on the individuals attempting to make sense of it, or practice it (Bueger, 2015). Only recently NATO included maritime security as an objective in its 2011 Alliance Maritime Strategy (NATO, 2011). Bueger (2015) further argues that: *"Maritime security can first be understood in a matrix of its relation to other concepts, such as marine safety, sea power, blue economy and resilience."* (Bueger, 2015, p. 1), where each of these concepts points to different dimensions of maritime security. However, these concepts described in the Maritime Security Matrix (Bueger, 2015) emphasize mostly the physical domain characteristics of maritime security. As the maritime domain is utilizing advancement in ICT, new vulnerabilities are introduced as the cyber domain[1] is emerging in importance (MoD, 2013). Further, as assets in the maritime domain are becoming more integrated with increased sharing of information between ICT systems, maritime security relies also on a mature understanding of cyber security to operate and navigate safely and securely.

The second term; cyber security, has its origin in information security. Information security is mainly concerned about securing the integrity, confidentiality and availability of information (Whitman and Mattord, 2011), while cyber security is mainly concerned with the availability and integrity of the cyber systems (Von Solms and Van Niekerk, 2013). A consequence is that cyber security, in addition to protect information transmitted or stored using ICT, also

[1] Cyber domain means an electronic information (data) processing domain comprising of one or several information technology infrastructures (MoD, 2013).

includes securing networks, hardware (HW) and software (SW) from unauthorized or malicious use. When ICT and OT are merging in the maritime domain, cyber security transcends into the operational domain of the navigator. Recent examples highlights that cyber-attacks have the potential to impact in the maritime domain by crossing the borders of cyber-physical interaction, resulting in loss of revenue (Maersk, 2017), or even inherent the power to provoke collisions by manipulating navigation information (Humphreys et al., 2008, Bhatti and Humphreys, 2014). While the catastrophic events as a result of cyber-attacks like explosions or fire are unlikely, errors introduced in a critical system such as the ECDIS are more likely. Such incidents have already been reported, with one of the latest example known as the Black Sea incident (Goward, 2017).

To summarize, MCS can be understood as a part of maritime security concerned with the protection from cyber threats of all aspects of maritime cyber systems, particularly concerning integrity and availability. In addition, MCS is concerned with the reduction of the consequences of cyber-attacks on maritime operations. Thus the means of MCS are not merely technological, but also consist of information and people.

2.2 Understanding MCS

According to Fitton et al. (2015) three elements of maritime cyber security should be taken into consideration to understand and mitigate cyber-attacks: Information, People and Technology.

These three elements are intertwined in forming the contemporary maritime cyber domain, and are further outlined in section 3. Technology is important to navigate and conduct all types of maritime operations, but also render possible the exchange of information between agents in the maritime sociotechnical system. In addition to the three elements of MCS, introduction of cyber systems in the maritime environment extends the reach of the maritime domain itself (Fitton et al., 2015). ICT creates connections between different locations in real time, with the result that the maritime domain is now, to a greater extent, converging with other domains like air, space and land. Hence, one important feature of the cyber domain is the ability to decouple location and presence (Floridi, 2017), creating the possibility of influencing both people and information in and through the cyber domain from distant locations. Therefore, when considering the concept of maritime security in the future, it will be vital to consider how the cyber domain is extending the maritime operating environment beyond a standard littoral boundary (Fitton et al., 2015).

By briefly exploring the features that cyber adds to the maritime domain, it is apparent that both the extended reach of the maritime domain and the mutual dependability between technology, people and information adds to the domain of interest for a navigator. This results in an extension of the SA requirements beyond the physically observable domain to conduct safe navigation.

3. Situational awareness for the modern navigator

With the modern ship bridge, the maritime navigator has gone through a paradigm shift concerning the number and use of displays and sensors when conducting the passage. Historically, the main task for the navigator is to find and fix the position of the vessel, while todays navigator monitors the vessel’s presented position on the ECDIS.

3.1 Technology

The displays and sensors on board ships are connected using computer networks, known as sensor integrators (SINT). An example of how a maritime navigation system used by the navigator to conduct a passage could be integrated is shown in Figure 1.

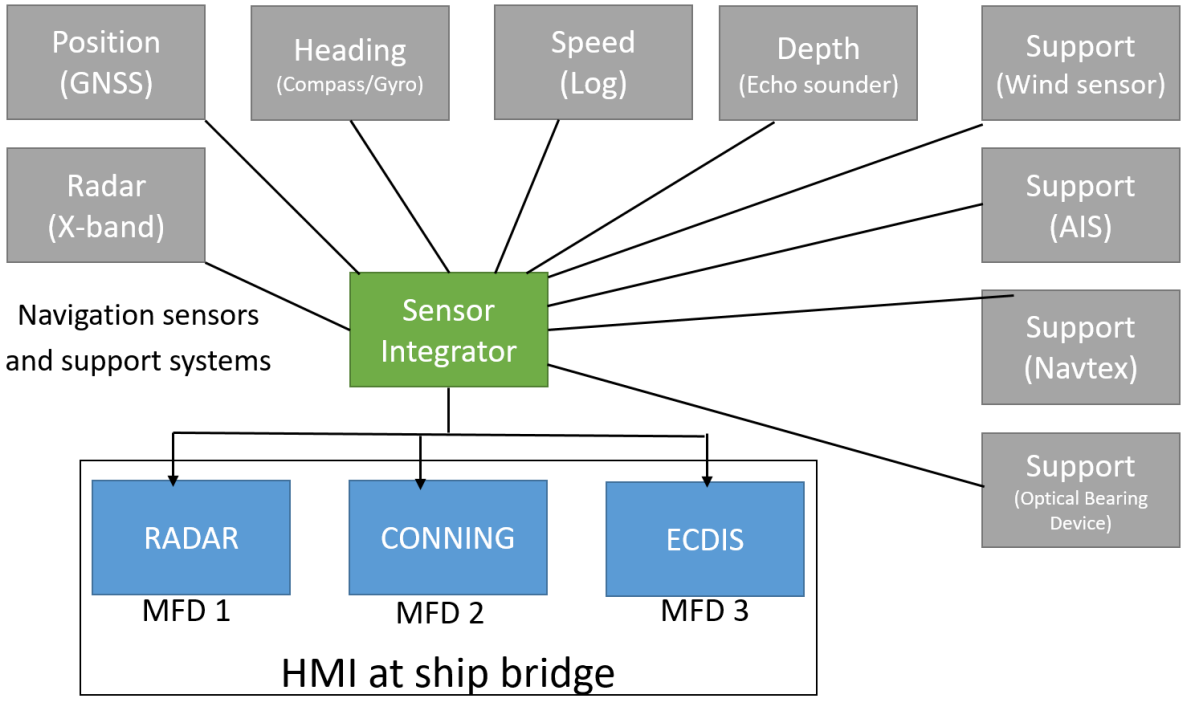

Figure 1: Example schematic of an integrated maritime navigation system.

The navigation system aims to provide information to increase the SA of the navigator in a timely manner. By providing an increased SA, the modern maritime navigation system enhances the safety of navigation by integrating information from sensors and provides augmented functions to avoid navigation accidents (Hareide and Ostnes, 2017).

Navigation systems and sensors on board ships has been networked, and information increasingly integrated, for many years. The International Maritime Organization (IMO) has released a voluntary-fitted performance standard for Integrated Navigation Systems (INS), to set the minimum requirements for the equipment in use. IMO Resolution MSC.252(83) (2007) describes the revised performance standards for integrated navigation systems, and the IMO recommends government assure that the INS should be installed on ships built after 2011. There are several functions within the INS, and the aim is to utilize and combine these functions to provide “added value” for the operator to plan, monitor and control the safety of the ship during its passage (IMO, 2007).

The sensors and systems within an INS include, but are not limited by (IMO, 2007):

- The Electronic Position Fixing System (EPFS), providing the absolute position of the vessel (for example Global Positioning System (GPS)).
- Heading Control System (HCS), which enable the ship to keep a preset heading, known as autopilot.
- Speed and Distance Measurement Equipment (SDME), providing the speed of the vessel (and thus distance).

- The ECDIS, used for chart presentation and presentation of relevant information for the navigator.
- RADAR system, used as a mean for terrestrial positioning.
- AIS, automatic tracking system used on ships and by vessel traffic services (VTS).
- Echo sounding system (ESS), providing the depth measurements for the vessel.
- Conning application providing information about the engine and manoeuvring status.
- Information distribution on Local Area Networks (LAN) and presentation of information on Multi-Function Displays (MFDs).
- Use of Communication channels such as Global Maritime Distress Safety System (GMDSS), which uses for example the NAVTEX to receive navigational messages, or other communication channels for distributing data such as satellite communication (SATCOM) or mobile broadband.

The Maritime Cyber Security demonstrator presented in this paper shows an attack against an INS, but the attack would also be relevant against a networked and integrated maritime navigation system, even though not compliant with IMO Resolution MSC.252(83).

3.2 Information

There has been a raised concern about the modern navigators` ability to conduct proper monitoring of the systems. As an example, the term “play-station mode” (Hareide et al., 2016) has been introduced to visualize the concern about the navigator focussing more on the displays than the surroundings of the ships.

The e-Navigation concept was introduced to enhance safety of navigation and efficiency of shipping (Hagen, 2017). E-Navigation is intended to promote safety, security and efficiency in global shipping, and a Strategic Implementation Plan (e-Nav SIP) has been introduced with a vision for e-Navigation (IMO, 2015). E-Navigation intends to meet the user needs through harmonization of on board navigation and information systems, communication and supporting shore services. It is also expected that the level of automation will increase and the amount of displays will be reduced with implementation of e-navigation. As an example is the SMART e-Navigation project for integrating chart and navigation information for coastal ships in Korea (Kim and Park, 2016).

Today the navigators' ability to determine and fix the position is mainly conducted through EPFS, such as Global Navigation Satellite System (GNSS) and most commonly used GPS. GNSS provides the absolute position of the vessel in more or less real time, and has been a revolution for the navigator. However, the navigator needs to be aware of several vulnerabilities such as signal interference and level of accuracy when using GNSS. This has led some to argue that the craftsmanship of navigation has decayed, because of an over-reliance in GNSS (Glomsvoll and Bonenberg, 2017, Norris, 2010). The craftsmanship of navigation for the modern navigator and the traditional navigator still shares at least one important factor of safe and secure navigation. The safe and secure navigation of a vessel relies on a navigator with a high level of situational awareness (SA). The purpose of e-Navigation and the INS is to provide the navigator with enhanced SA through timely and correct information. However, with the technological vulnerabilities introduced we argue that the SA requirements also change.

3.3 People

High degree of SA supports handling unexpected incidents (Wickens, 2002). According to Endsley (1995), SA constitutes three levels; perception, comprehension and prediction. The ability to develop and maintain a high level of SA vary significantly between people and tasks (Endsley and Garland, 2000) and when the cyber domain has entered the playground, Endsley's model of SA has been criticised for being too physical domain oriented, missing vital features that the cyber domain brings (Alcaraz and Lopez, 2013). In the same vein, cyber oriented SA papers have been criticised for being concerned with aspects related to SA that in fact are only sub components, i.e. sensors, recognized cyber picture, strategic picture, physical operations etc., leaving the overall SA unmentioned (Franke and Brynielsson, 2014). According to Franke & Brynielsson (2014) the technical and cognitive sides of SA are closely related and somewhat intertwined, meaning that cyber information needs to be combined with other information to make sense and to obtain full understanding of the situation (Franke and Brynielsson, 2014).

Wickens (2002) argues that in the context of aviation, the three components of SA are spatial awareness, task awareness and system awareness. The importance of awareness of the system was already mentioned by Adams et al (1995), in relation to a growing concern of complex systems taking the operator partly “out of the loop”. The maritime domain has similarities with aviation, and several of the conditions and restraints are coinciding (Hareide and Ostnes, 2017). Spatial awareness consists of the environment the navigator must adhere to, and incorporates all the variables that the navigator must address to conduct a safe and efficient passage. The maritime environment is dynamic, and variables will alter during the passage. The navigator must take into account the vessel’s current task (mission), which consist of navigation, seamanship, communication with other internal and external agents to conduct the task and system management (for example fuel management). System awareness for the navigator consists of the navigator’s ability to understand and be aware of the state of the systems on the bridge. In aviation, the pilot usually needs not be aware of the system status, unless an unexpected situation arises (Wickens, 2002, p. 131). With the introduction of e-Navigation and cyber systems on board a vessel, a high degree of system awareness is increasingly important in order to maintain SA. Both the vessel and the maritime environment are complex and dynamic, as are the systems within the vessel. One of these systems is the INS (Figure 1), which the navigator continuously operates. The complexity of the system, often coupled with poor design, makes system awareness difficult to maintain (Sarter and Woods, 1995, Hareide and Ostnes, 2016). When understanding the system, and in this specific context the INS, it is important to relate it to the integrity, confidentiality and availability of relevant and time-crucial information flowing on the network of the INS. Thus, MCS is related to the navigator’s SA through system awareness, illustrated in Figure 2.

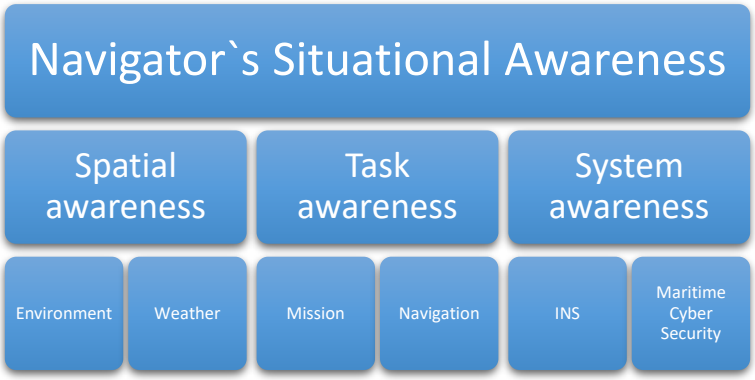

Figure 2: The relation between SA and system awareness.

Note that the bottom line of Figure 2 is meant as examples, and is not complementary as other examples could have been used. According to Endsley's theory, level three SA gives the person ability to project future states and events (Endsley, 1995). In a cyber-security context this will be the ability to; *"anticipate, detect and respond to unforeseen situations (failures or attacks) before they can cause disruptions"* (Alcaraz and Lopez, 2013, p. 31). While this might seem too much to expect of the navigator, we think that simple efforts focussing on understanding and comprehension of the cyber threat could help mitigate large portions of the contemporary cyber-attacks against an INS. With approximately 70% of breaches exploiting non-technical vulnerabilities (Deutscher et al., 2017), the navigator cannot afford to disengage in gaining cyber competence and leaving it to be the sole responsibility of the ICT department. Hence, there is currently a need to make the intangible cyber threat tangible, in order to add to the competence of the navigator instead of creating more confusion and uncertainty. *"Preventing, identifying and defending against cyber-attacks requires educating, training and drilling staff, so as they can efficiently respond to attacks, spot errors and continue to operate under cyber-attack conditions"* (Fitton et al., 2015).

4. Using the Cyber Kill Chain to demonstrate a cyber-attack against an INS

This project was conducted as a cooperation between state-actors and industry. In order to facilitate and conduct the MCS demonstrator, the composition of the working group was important, and a need for different types of Subject Matter Expert (SMEs) was identified. The working group in this project consists of one engineer from the ECDIS developer, two cyber specialists, one navigation specialist and three students. Two of the participants have served as sailors with The Norwegian Royal Navy. The project started in February 2017, data gathering was conducted in August 2017 and findings were analysed and discussed in the fall of 2017 with the project ending late 2017. The timeframe of such a project can be reduced when applying the initial findings from this paper.

4.1 Data Collection

An important resource to allocate is a vessel where to conduct the cyber-attack. The vessel presented in this paper is equipped with commercial of the shelf (COTS) computers with the Windows 7 operating system, and a commercial available INS delivered by a contractor as the target system. The data was collected in a real-time environment on board a ship fitted with an INS as shown in Figure 1. Figure 1 outlines the complexity, and shows how several sensors are interconnected through a sensor integrator (SINT). The navigation data is provided to the INS via a redundant LAN, providing all the MFDs with the information from the sensors interconnected through the SINT.

The passage was carried out during three days in late August, in Norwegian littoral waters in the vicinity of Bergen. The data collection was done around Bergen which had 87156 port calls in 2015 according to Port of Bergen (POB, 2015).

The area is characterized by confined waters challenging for navigation, due to its high amount of islands, skerries and underwater rocks. For the purpose of the experiment the procedure was documented by means of video recording and pictures, this documentation will not be presented in this article in order to anonymize the vessel and the manufacturers.

The first step was to gather the participants for an initial workshop where the overall concept for the study was discussed. In order to make swift progress the workgroup decided to separate the technical and operational part of the project, leaving one part working on how to spoof the ships position presented in the INS from a technical point of view, and the other part working on the plausibility of gaining access and discussing operational consequences.

The exploration of the competencies needed to navigate in the 21st century, with regard to implications caused by the cyber threat, can be performed by putting your mind into the point of view of the potential attacker. This can be achieved by using the Cyber Kill Chain from Lockheed Martin (Hutchins et al., 2011) as the conceptual framework, which consist of seven 4phases:

1. *Reconnaissance* such as harvesting email addresses, conference information, etc.
2. *Weaponization* such a coupling exploit with backdoor into deliverable payload.
3. *Delivering* weaponized bundle to the victim via email, web, USB, etc.
4. *Exploiting* a vulnerability to execute code on victim's system.
5. *Installing* malware on the asset.
6. *Command and Control* channel for remote manipulation of victim.
7. *Actions on objectives* conducted with "hand on keyboard" access, intruders accomplish their original goals.

4.2 Reconnaissance

The first part of the Cyber Kill Chain is reconnaissance. This was conducted in a workshop where the participants brainstormed potential attack vectors of the system. The participants in the workshop had in depth knowledge of the technical and operational aspects of the system, navigational practice and routines regarding updates of HW and SW on board the specific vessel. In this initial phase we decided that spoofing the position provided by the EPFS by a small amount would be one plausible goal of an adversary with intent and capacity. The effect could be bolstered by triggering the offset at a predefined point or by means of remote command utilizing the INSs merging of auxiliary systems like for example AIS or NAVTEX (Figure 1). By drawing off knowledge about the updating routines and SME systems knowledge an array of different cyber-attack vectors was identified. These vectors can be roughly be divided into two: 1; If one has direct access to the system and 2; If one can gain indirect access to the system. For the purpose of this project we decided to analyse what could be possible if we had direct access to the system, and rather discuss the plausibility of gaining indirect access. The discussion is conducted by analysing the routines performed by developers, technicians and operators with access to the on board computers used in the INS (known as Operator Stations – OS). From an operational perspective, both an indirect access and direct access are plausible vectors of attack. The identified attack vectors are laid down in Figure 3:

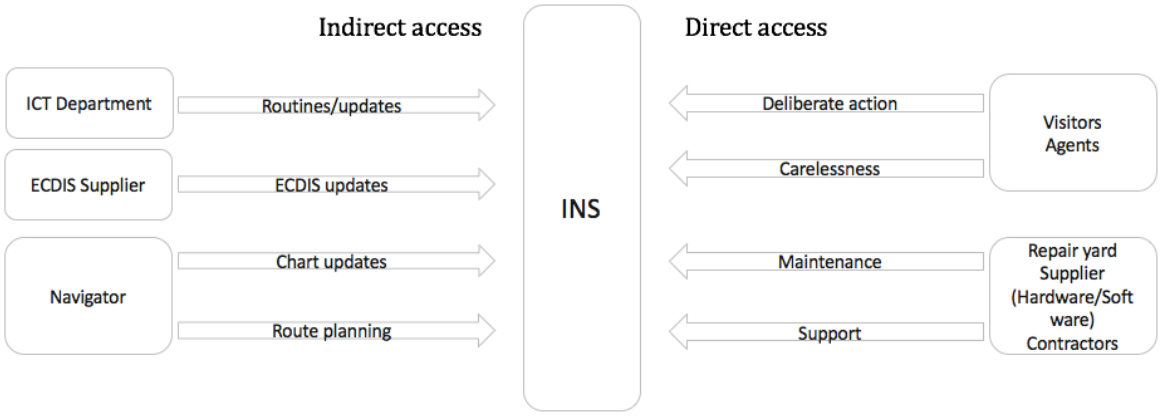

Figure 3: Potential attack vectors towards the INS.

The attack vectors are in general the same for all vessels, but there will be some difference when it comes to the age and maintenance routines of different types of vessels. Figure 3 provides as an example of how one could map the different possible threat vectors within the MCS domain for a vessel. These attack vectors assume the INS does not have any outbound connections. However, reports (NCC 2014, Baranuik 2017) indicate that connecting the INS to the internet is becoming increasingly common, providing even more attack vectors.

4.3 Weaponization

The weaponization phase was performed by the cyber specialist by utilizing open source information on how to develop the attack (Lund et al., 2018, in review). The cyber specialist used a laptop with the current windows version and the ECDIS application installed in order to test the attack during development. The rest of the participants engaged in conceptualizing the notion of maritime cyber security and conducting focus groups with navigators to disclose cyber security awareness and current routines, and understanding of routines to mitigate cyber threats.

4.4 Delivery, exploitation and installation

Ways of gaining access to the system was identified in the initial workshop and the potential access points is shown in Figure 3. Once the attack was properly developed it was delivered through an USB port using a special built UBS device. First the USB device acted as a mouse and keyboard to log out of ECDIS and entering the operating system. The malware was installed on the windows operating system and restarted the computer. Once installed it acted as a man in the middle between the sensory data input and the ECDIS application. The duration of this procedure was 5 minutes and 17 seconds, however improving the delivery could reduce the time needed to infect the system (Lund et al., 2018, in review). The end state is an ECDIS that seemingly has no faults and works as normal. Using the VirusTotal site (www.virustotal.com), the malware was tested against 60 of the most common anti-virus programs available for purchase. Only two of these detected any suspicious code in the malware, while the remaining 58 categorised the malware as “clean”. An anti-virus program installed would therefore not be sufficient protection against a tailored cyber-attack like this.

4.5 Command & control and action on objectives

The INS is usually considered an offline system. Therefore, command and control communication between malware and attacker through Internet connection is not possible. In order to solve this problem, the malware where programmed to trigger on a specific position, so that when the ship crosses this predefined line, the malware starts to inject faulty values. The result is the ECDIS showing an increasingly faulty position.

5 FINDINGS

The malware was successfully installed on the computer by putting the USB device into an open and available USB slot. The full technical procedure is explained in Lund et al. (2018, in review). The malware was installed on the computer running the ECDIS SW, and successfully manipulated GPS input causing the ECDIS to present a faulty position during the passage.

The malware was triggered when the ship crossed a predefined and pre-programmed position in latitude (lat) and longitude (long). The displayed position during this experiment was offset with a rate of 0,0004 minutes (approximately 0,8 meters) per second towards the northeast (045 degrees). This can be viewed in Figure 4 of the ECDIS, where the left-side picture is spoofed, and the real position can be viewed in the right-side picture.

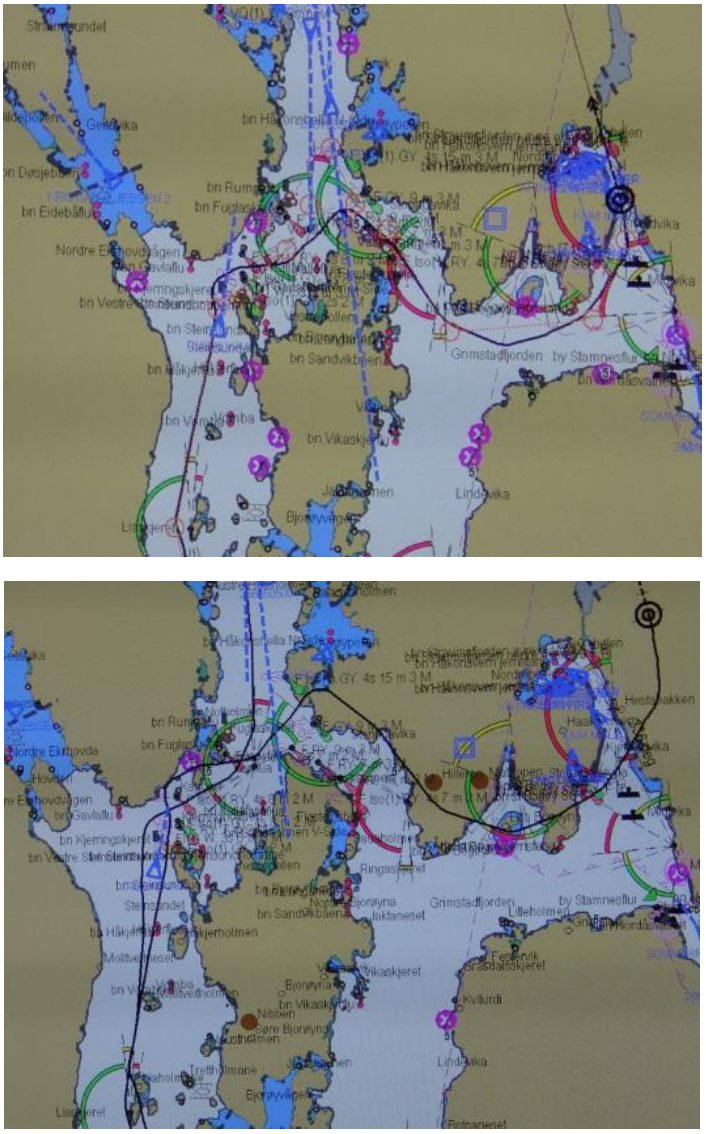

Figure 6. Upper print screen picture shows the ships actual track, lower screen picture shows the infected operator stations ship track.

A shutdown of the navigation computer was performed by triggering the malware at a second predefined position (lat/long), leaving the navigator unable to restore the proper ECDIS function during the passage. When restarting the computer, the malware hampered the SW ability to operate, implied by a “blue screen”.

The attack was also conducted when the vessel operated in “track mode”, which means that the autopilot is following the pre-planned route. When the position was spoofed, the autopilot corrected the spoofing by turning the vessel, thus taking the vessel away from the actual pre-planned route, which would eventually result in a “controlled” grounding of the vessel.

6 DISCUSSION

The introduction of ICT in the maritime domain expands the notion of maritime security by introducing cyber domain challenges. Therefore, it is fair to say that MCS has to be included as a part of maritime security measures. However, the cyber domain is proving to cross cyber-physical borders and hence cannot be treated as a technological issue alone. The implication of this insight is that maritime cyber security has to be considered something more than an ICT department issue; it also includes people and information. As proven in this demonstrator the most crucial phase of a cyber-attack is the reconnaissance phase were an attacker utilizes whatever means available to gain critical information about the target system. This can include information available online, information gained through social engineering or even by gaining physical access to the target system. Hence, being off-line does not exclude the possibility of being exposed to targeted attacks. From a MCS perspective this means that if one can deny a threat actor information in the reconnaissance phase, this will reduce the risk of eventually experiencing an attack. However, this seems to be reliant on a combination of measures including enhancing competence of personnel operating the systems; in this case the navigator.

Introducing the cyber domain in the maritime context changes something; it adds something. It adds complexity and dependency on technology (e.g. the removal of paper maps), and the operator’s competence requirement is changing from traditional navigation with analogue tools to also requiring digital competence and system awareness. This leads us to evaluate if introducing INS and e-Navigation also changes the competence requirements for the navigator. The demands for spatial and task awareness may be similar, while demands for system awareness changes. This can be exemplified by comparing the “use of ECDIS” and the “understanding of ECDIS”. Today one could argue that the first is the focus, to use and harness the advantages of the INS. However, from a competence perspective; to use and to understand the system is two different approaches to education and training. The need for a high degree of situational awareness is essential to be able to make good informed navigation decisions. When introducing INS and enabling the cyber domain we add the need to be situational aware of the status of the system and the limitations and possibilities it presents. If one lacks system awareness, one would lack a vital part of the overall situational awareness and potentially present a risk factor rather than a risk reduction factor. So in order to utilize the human capacity to be the strongest link in the MCS chain, MCS has to become a part of education and training in order to enhance the navigator's competence by increasing system awareness. Using the cyber kill chain to conceptualize and demonstrate MSC can be a cost

efficient and beneficial way to expose navigators to the threat and thus offer an easy solution to a growing challenge.

This experiment demonstrates that cyber-attacks against the INS is relatively easily achievable. The security of the INS relies heavily on physical protection, while the INS itself is quite open once access has been established. Initially, the reconnaissance phase is the most resource consuming for a potential attacker. This is where the attacker has to gain knowledge about the system and the routines of the crew in order to obtain information like for example passwords for login to higher maintenance levels etc. However, ECDIS systems are available for purchase on the open market and technical documentation are relatively easily available, and sometimes even passwords can be available online (US-CERT, 2013). The discussion whether this is possible is more a discussion about the attacker's intent, motivation, resources and persistence, than a discussion about whether this information is obtainable or not. Once the needed technical documentation is obtained, an attacker would benefit from the ability to test the malware before installation. In this project the cyber specialist used less than two months' worth of man hours to familiarize with the system and to develop the attack. Even if the cyber specialist was given the ECDIS SW and had technical support from the supplier, this would also be within reach for a state actor or a large criminal organisation. The discussion then becomes if this would be plausible if the cyber specialist didn't have the above-mentioned resources available. It is quite clear that a teenager in his bedroom or a computer specialist in isolation would not have been able to perform such an attack.

Once the initial two phases are completed, the next critical phase is getting the malware installed. The ECDIS requires updates to sustain integrity over time, and in addition the ECDIS SW runs on a Microsoft Windows based operating system that also requires updates and patching regularly. The updating of charts and routes require sometimes weekly or even daily updating and interaction between other computers through USB drives. Most vessels use the ECDIS as an offline system, and all updates are done by USB sticks. This results in a lot of interaction between the INS and auxiliary systems. Taken into account that the systems seldom have anti-virus and protective measures (Baraniuk, 2017), this leaves the part of getting into the system with the malware less demanding for an attacker. If not direct access can be gained, an unknowing navigator or maintenance personnel could potentially be used as the messenger, with reference to Figure 3. Once installed, the malware can trigger on a predefined position and therefore requires no more interaction with the attacker. The threat remains dormant until the activation criteria has been met.

The end state of this attack is to create uncertainty for the navigator when the position in the INS/ECDIS, and the observed position is not correlating. This may in turn reduce the navigators trust in the ECDIS and heighten the workload if the position deviation is noticed at all (Hareide, 2013). This will deter the SA of the navigator, and it could contribute to a dangerous and undesirable event in relation to the navigation of the vessel. In a worst-case scenario the position deviation could be tailored to the ship and the waters in such a way that the deviation is difficult to detect and a fast enough to run the ship aground or ashore.

For the navigator to better understand MCS, the conduct of the process as described in the cyber kill chain will establish a better system awareness, which in turn increases SA for the navigator and can contribute to the navigators' resilience in case of a cyber-attack. This will have implications for education and training of navigators, and we argue that an increased

focus on system knowledge and understanding is needed with the changing working environment with introduction of more technology for the navigator. With an increased system awareness, the navigator will understand the importance of integrity monitoring and system awareness in the conduct of a passage.

7 CONCLUSION

The study explains and gives a working definition of Maritime Cyber Security, and identifies the relationships between MCS and safe and efficient navigation through system awareness as a part of the navigator's overall SA. The importance of high system awareness for the navigator operating the INS is laid down, as a contribution to increase the SA of the navigator. Further the MCS demonstrator is explained and put into context.

The demonstrator utilizes the cyber kill chain to address the call for closing the gap between the emerging threat of cyber-attacks and the competence needed at operator level. By utilizing the cyber kill chain, the awareness of the emerging cyber threat to the maritime environment can be identified. When the threat is identified, measures can be taken to mitigate the threats. The demonstrator is a relevant example of how an actor with resources and motivation can spoof an INS.

By understanding the possibilities and limitations within the system in use, the INS, this will provide an increased system awareness and thus increase SA and ultimately providing a safe and efficient passage.

7.1 Further work

The OEM will patch the current SW by implement the current findings in existing SW, and the crew of the vessel will provide physical adjustments on equipment on board (for example lock-down procedures and use of tampering tape) to prevent access to system for outsiders (attackers). The findings from this study will be implemented in current curriculum for maritime navigators at the Royal Norwegian Naval Academy to improve system knowledge and thus contributing to a higher level of SA. In future development of the demonstrated cyber-attack, investigate other vectors of delivery, as well as using the Automatic Identification System to exercise remote command and control of the malware.

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8.2 Ethical Standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and

with the Helsinki Declaration of 1975, as revised in 2008. All details of the cyber-attack have been disclosed to the manufacturer of the INS.

REFERENCES

Adams, M. J., Tenney, Y. J. & Pew, R. W. (1995). Situation Awareness and the Cognitive Management of Complex Systems. *Human Factors,* 37**,** 85-104.

Alcaraz, C. & Lopez, J. (2013). Wide-area situational awareness for critical infrastructure protection. *Computer,* 46**,** 30-37.

Baraniuk, C. (2017). How hackers are targeting the shipping industry. Available: http://www.bbc.com/news/technology-40685821 [Accessed 22.08.2017].

Bhatti, J. & Humphreys, T. E. (2014). Covert control of surface vessels via counterfeit civil GPS signals. *University of Texas, unpublished*.

BIMCO, CLIA, ICS, Intercargo, Intertanko, OCIMF & LUMI. (2017). Guidelines on Cyber Security onboard Ships. *In:* BIMCO (ed.) Version 2.0 ed. Bagsvaerd.

Bueger, C. (2015). What is maritime security? *Marine Policy,* 53**,** 159-164.

Demchak, C., Patton, K. & Tangredi, S. J. (2017). Why Are Our Ships Crashing? Competence, Overload, and Cyber Considerations. Available: http://cimsec.org/ships-crashing-competence-overload-cyber-considerations/33865 [Accessed 12.09.2017].

Deutscher, S., Bohmayr, W. & Asen, A. (2017). Building a Cyberresilient Organization Available: https://www.bcgperspectives.com/content/articles/technology-digital-building-a-cyberresilient-organization/.

Dyryavyy, Y. (2014). Preparing for Cyber Battleships - Electronic Chart Display and Information System Security. NCC Group.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human factors,* 37**,** 32-64.

Endsley, M. R. & Garland, D. J. (2000). *Situation awareness analysis and measurement*, CRC Press.

Fitton, O., Prince, D., Germond, B. & Lacy, M. (2015). The future of maritime cyber security. Lancaster University.

Floridi, L. (2017). Digital's Cleaving Power and Its Consequences. *Philosophy & Technology,* 30**,** 1-7.

Franke, U. & Brynielsson, J. (2014). Cyber situational awareness–a systematic review of the literature. *Computers & Security,* 46**,** 18-31.

Gard. (2016). Cyber Security - managing the threat. Available: http://www.gard.no/Content/21112216/CyberSecurity [Accessed September 2016].

Glomsvoll, O. & Bonenberg, L. K. (2017). GNSS jamming resilience for close to shore navigation in the Northern Sea. *The Journal of Navigation,* 70**,** 33-48.

Goward, D. (2017). Mass GPS Spoofing Attack in Black Sea? Available: http://maritime-executive.com/editorials/mass-gps-spoofing-attack-in-black-sea [Accessed 10.08.17].

Hagen, J. E. (2017). *Implementing e-Navigation,* Norwood, Artech House.

Hareide, O. S. (2013). *Control of ECDIS (electronic charts and display information system) on high speed crafts in littoral waters.* MSc, University of Nottingham.

Hareide, O. S. & Ostnes, R. (2016). Maritime usability study by analysing Eye Tracking data. *Internation Navigation Conference Proceedings***,** 17.

Hareide, O. S. & Ostnes, R. (2017). Scan Pattern for the Maritime Navigator. *TransNav 2017***,** 10.

Hareide, O. S., Ostnes, R. & Mjelde, F. V. Understanding the Eye of the Navigator. (2016) *In:* NAVIGATION, N. I. O., ed. European Navigation Conference, 2016 Helsinki. Confedent International.

Humphreys, T. E., Ledvina, B. M., Psiaki, M. L., O'hanlon, B. W. & Kintner Jr, P. M. (2008). Assessing the spoofing threat: Development of a portable GPS civilian spoofer. Proceedings of the ION GNSS international technical meeting of the satellite division, 2008. 56.

Hutchins, E. M., Cloppert, M. J. & Amin, R. M. (2011). Intelligence-driven computer network defense informed by analysis of adversary campaigns and intrusion kill chains. *Leading Issues in Information Warfare & Security Research,* 1**,** 80.

IMO. (2007). Resolution MSC.252(83): Adoption of the Revised Performance Standard for Integrated Navigation Systems. London. Available: http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Maritime-Safety-Committee-(MSC)/Documents/MSC.252(83).pdf.

IMO. (2015). Draft e-Navigation Strategy Implementation Plan (SIP). *In:* http://www.imo.org/en/ourwork/safety/navigation/documents/enavigation/sip.pdf

Kim, J. & Park, Y.-Y. (2016). An Integrated Approach to Korea's e-Navigation Communication Infrastructure. *International Information Institute (Tokyo). Information,* 19**,** 643.

Lund, M. S., Hareide, O. S., Jøsok, Ø. & Skare, K. E. (2018) An attack on an integrated navigation system. USENIX Security Symposium, submitted, 2018.

Maersk. (2017). Press release Interim Report Q2 2017. Copenhagen. Available: http://investor.maersk.com/releasedetail.cfm?releaseid=1037421.

Maritime Accident Investigation Board, MAIB. (2014). Report on the investigation of the grounding of Ovit in the Dover Strait. Southampton. Available: https://assets.publishing.service.gov.uk/media/547c6f2640f0b60244000007/OvitReport.pdf.

MoD, Finland. (2013). Finland´s Cyber security Strategy. *In:* COMMITTEE, S. O. T. S. (ed.). Helsinki: MoD.

NATO. (2011). Alliance Maritime Strategy. Available: http://www.nato.int/cps/en/natohq/official_texts_75615.htm.

Norris, A. (2010). *Integrated Bridge Systems vol 2 ECDIS and Positioning,* London, Nautical Institute.

Port of Bergen. (2015). Annual Report. Bergen. Available: https://bergenhavn.no/om-bergen-havn/arsrapporter/.

Sarter, N. B. & Woods, D. D. (1995). How in the World Did We Ever Get into That Mode? Mode Error and Awareness in Supervisory Control. *Human Factors,* 37**,** 5-19.

Us-Cert. (2013). Risks of Default Passwords on the Internet. *In:* SECURITY, D. O. H. (ed.). Available: https://www.us-cert.gov/ncas/alerts/TA13-175A.

Von Solms, R. & Van Niekerk, J. (2013). From information security to cyber security. *computers & security,* 38**,** 97-102.

Whitman, M. E. & Mattord, H. J. (2011). *Principles of information security*, Cengage Learning.

Wickens, C. D. (2002). Situation awareness and workload in aviation. *Current directions in psychological science,* 11**,** 128-133.