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The use of radar and AIS in anti-collision on a modern IBS in the Norwegian Navy

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Content

Abstract

Navigation in the littoral waters of Norway is based on long traditions. All naval units spend much time and effort to navigate faster, safer and tactically clever. For decades radar has been the most important tool to ensure navigation at an acceptable risk level.

After the introduction of computer based integrated bridge systems, it was possible to give the navigators a new set of tools, and it was technologically possible to do things faster and with a higher level of automation and precision. However, the introduction of new technology did not only lead to a safer and more efficient navigation. The statistics revealed that during the last decade, collisions still happened at approximately the same frequency. Most of the collisions reports express that violations of "the International Regulations for Preventing Collisions at Sea" (COLREG) occur. The reports also describe incorrect use of radar and AIS and lack of understanding of the systems.

In addition to visual evaluation, radar and AIS are the most important aids to avoid a collision. The radar is well known, but has been constantly developed. Even if AIS is relatively new, most ships have installed it, but it is not always taken maximum advantage of.

In order to investigate how radar and AIS are utilised in the Norwegian navy, the fieldwork consisted of observation of live navigation on board the Skjold class and in the simulator at NNC. In addition 19 officers were interviewed by means of a questionnaire to evaluate the level of knowledge within radar and AIS.

The findings indicate that all the different aids provided in an IBS to avoid collisions are not fully understood and not fully utilised. Some automatic functions are never used and hardly ever explored. Visual observations were the most important and most used input factors to create a SA before decisions were made. The electronic information provided by radar and AIS was not always utilised to achieve an optimal SA.

However, all potential collisions incidents in the field tests were handled in a professional and safe way.

Acknowledgement

During the work with this thesis I have received useful encouragement and support from all my colleagues and friends. Many of my colleagues have expressed that it was about time that this area was scientifically looked into.

A crucial part of the thesis was the field tests that were carried out at the Norwegian Corvette Service, on the Skjold class FPBs which hosted the live sailing and the Navigation Centre at the Royal Norwegian Naval Academy who accommodated and supported the simulator tests. I am utterly grateful and impressed by the warm welcoming, the willingness to support and the openness in their response.

Not many people possess the same level of knowledge in this area as Prof. Dr. Andy Norris and I am especially thankful for his professional guidance. My second mentor, Dr Chris Hill has been supervising the project from the University of Nottingham, and I appreciate his support.

Finally, I would like to thank my family, Anne Linda, Lars, Martin and Ingrid for backing me up and providing constructive feedback. I am especially grateful to my wife, Anne Linda for skilled guidance, her patience and for her untiring work to correct my English.

Abbreviations

AIS	-	Automatic Identification System
ARPA	-	Automatic Radar Plotting Aid
ATON	-	Aids to Navigations
CO	-	Commanding Officer
COLREG	-	Collision Regulations
COG	-	Course Over Ground
CPA	-	Closest Point of Approach
EBL	-	Electronic Bearing Line
ECDIS	-	Electronic Chart Display and Information System
ETA	-	Estimated Time of Arrival
FPB	-	Fast Patrol Boat (Skjold class coastal corvettes)
FF	-	Fridtjof Nansen class frigate
GPS	-	Global Positioning System
GNSS	-	Global Navigation Satellite System
HNoMS	-	His Norwegian Majesty's Ship
HSC	-	High Speed Craft
IBS	-	Integrated Bridge System
IEC	-	International Electrotechnical Commission
IHO	-	International Hydrographic Organization
IMO	-	International Maritime Organization
INS	-	Integrated Navigation System
INaS	-	Inertial Navigation System
ISM	-	International Safety Management Code
KTS	-	Knots (1knot = 1nm/hour)
MAIB	-	Marine Accident Investigation Branch
MCA	-	Maritime and Coastguard Agency
MFD	-	Multi Function Display
MoD	-	Ministry of Defence

MMSI	-	Maritime Mobile Service Identity
MSC	-	Maritime Safety Committee
MTBTS	-	Norwegian Corvette Service Training Centre
MTBV	-	Norwegian Corvette Service
NM	-	Nautical Mile (1nm = 1852 metres)
NNC	-	Norwegian Navy Navigation Centre (RNoN)
NMD	-	Norwegian Maritime Authority
NUP/FT	-	North Up Fixed Centre, True Vector and Trails
OBD	-	Optical Bearing Device
OOW	-	Officer of the Watch
PI	-	Parallel indexing
RAIM	-	Receiver Autonomous Integrity Monitoring
RCS	-	Radar Cross Section,
RHIB	-	Rigid-Hulled Inflatable Boat
RNoN	-	Royal Norwegian Navy
RNoNC	-	The Royal Norwegian Naval Academy Navigation Centre
SA	-	Situation awareness
SMP	-	Navy Military Publication (Sjøforsvaters militære publikasjon)
SOLAS	-	Safety of Life at Sea
SOTDMA	-	Self Organizing Time Division Multiple Access
STCW	-	Standards of Training, Certification, and Watchkeeping
TCPA	-	Time to the Closest Point of Approach
TT	-	Target Tracking
UTC	-	Coordinated Universal Time
VTS	-	Vessel Traffic Services

Figures

Tables and diagrams

1 Introduction

1.1 Background

Professional navigation is in general a skill that requires a combination of long education, much training, and a lot of experience. Even if that is a fact, there is a constant dynamic that challenges the navigators when making crucial decisions based on their current situation awareness and best judgement. The solution is not always straight forward; there are always several solutions to a situation that all might solve the situation. Navigating within the skerries and cruel littoral waters of the long Norwegian coastline does not make the situation easier, and combined with bad weather in different seasons, there is a potential risk of accidents.

During the last decade, the evolution within the maritime domain has been substantial, being very well described by Lee and Sanquist who already 13 years ago saw the trends.

> *"Naval maritime navigation is in a state of transition which could affect the safety and performance of ships and their crews. Paper charts are replaced by electronic charts, crew sizes are reduced, and ship speeds are increasing"(Lee and Sanquist, 2000).*

The quotation is generally recognised as still valid for the Norwegian Navy and probably also for other navies and civilian maritime shipping.

In worst case, a collision may cost human lives, but can also cause pollution, and be costly for the ship owners. In 1977 the International Rules for the Prevention of Collisions at Sea 1972 (COLREG) (IMO, 1972), came into force, and combined with requirements under IMO's Standards of Training, Certification, and Watchkeeping Code (STCW) (IMO, 1978), and some parts of the International Safety Management Code (ISM) (IMO, 2010), collisions could theoretically be avoided. This is also confirmed in the safety study carried out by Marine Accident Investigation Branch which declares that collisions could hypothetically be avoided if every vessel abided by the International Rules for the Prevention of Collisions (MAIB, 2004).

However, it is still a fact that collisions happen on a regular basis. Despite constant development of better radars with more sophisticated technology and the introduction of Automatic Identification System (AIS) specialised in aiding navigators to achieve good situation awareness, there is still a number of accidents in Norway and in other parts of the world. The introduction of Integrated Bridge Systems (IBS) and the transformation from paper chart to integrated electronic chart systems should facilitate even better decisions in challenging situations, but that might not always be the case (NNC, 2007, Norris, 2008).

The Norwegian Maritime Directorate (NMD) which has jurisdiction of ships registered in Norway and foreign ships arriving Norwegian ports, reported 24 collisions in 2010 which is an increase compared to 2009 and 2008.

In 2004 the Marine Accident Investigation Branch (MAIB) in the United Kingdom also issued a study of collisions, groundings, contacts and near collisions that took place in the timeframe 1994 – 2003. This study revealed that the COLREG were contravened in most collisions and that the most common contributory factors in all the collisions were poor lookout and poor use of radar (MAIB, 2004).

1.2 Research Focus

Unfortunately, the Royal Norwegian Navy (RNoN) also has considerable experience with groundings, collisions, and other navigation accidents. In 2006 a large study was carried out, singling out the different factors causing the accidents in the RNoN over a long period (Gould et al., 2006). Since 1989, the estimated incidence of major navigation mishaps (not only collisions) in the RNoN has been around six vessels per year (MOD, 2005). As in the civilian domain, groundings are dominant, but there have been several collisions also in the RNoN. The exact statistics for the RNoN are not available due to military regulations.

After 2005 the numbers of operational ships in the RNoN has decreased and several new projects have been in progress, resulting in less operational time on patrol and a subsequent reduction in the groundings and collisions. Nevertheless, the challenges are still present. The RNoN is going through a modernisation period, and in time, all ships will have state of the art Integrated Bridge systems (IBS), which are based on type approved equipment for the civilian shipping market. Hence, it is reasonable to assume that the Norwegian navy will experience much of the same effects as any civilian ship.

The focus will therefore be to investigate and analyse how radar and AIS are being utilised in the Norwegian Navy as anti-collision aids. The thesis will also concentrate on the knowledge that is relevant to and basis for the understanding and operation of radar and AIS. The results will be seen in context with the recent and future development in the navy, focusing on modern IBS fitted ships.

1.2.1 The purpose of the project and possible results

The purpose of this research is to register navigators' performance on modern IBS in the Norwegian navy when making use of the available means to avoid collision.

The research will present an overview of the knowledge within the area of radar and AIS and the thesis will show whether it is necessary to adjust the level of radar and AIS training and operation. The result might also discover challenges within the IBS on a broader spectre. Furthermore, it might also suggest what kinds of changes are necessary to increase the navigation safety in the Norwegian Navy.

1.3 Overall research aim and individual research objectives

1.3.1 The thesis

How are radar and AIS utilised in anti-collision on modern Integrated Bridge Systems (IBS) in the RNoN, within Norwegian littoral waters?

1.3.2 Research aim

The research aim is to identify areas within use of AIS and radar that can enhance safe navigation and hence reduce the probability for a collision to a minimum.

1.3.3 Research objective

The research aims to investigate to what extent radar and AIS are utilised in anti-collision. The overall purpose of this research is to understand the role of radar and AIS in anti collision on board modern naval ships equipped with IBS and to investigate into the knowledge of the operators to find if they are adequately educated and trained for the task.

1. *Identify and examine* the use of AIS and radar in anti-collision by live observations and simulated tests.
2. *Explore* relevant anti-collision radar and AIS knowledge.
3. *Formulate* recommendations for radar and AIS education and training.

1.4 Research value

A substantial evolvement within navigation has been going on for many years, and several ship owners and institutions have experienced this new technology entering the shipping world. There has been a clear need to investigate and discuss the effect of this new technology; one event in London even called the conference ECDIS Revolution. (ECDIS-Revolution, 2013)

The publication SNP-500 (NNC, 2012) issued by the Norwegian Navy Navigational Centre (NNC) clearly stats that a technological revolution has occurred and the guidelines in the publication are made to make it easier for the users to understand the changes and how to use the equipment.

A presentation from the NNC (2009) sums up the new challenges by this "bumper sticker:"

> *"We have evolved from 6 knots with the Vikings*
> *to 60 knots with Bill Gates".*

From this statement one can start to realise the challenges piling up.

The RNoN decided early on to follow the modernisations process, equipping all the naval ships with modern navigational equipment in modern IBS. This transformation also leads to the need to review the well known and traditional procedures developed over decades.

This research will look into one area that has been affected by this new modernisation. It is therefore important that the research is done in time before possible, inadequate new procedures are randomly emerging. The thesis will shape the basis for the change in how the Navy will make effective and safe navigation in the future.

1.5 Outline Structure

Chapter 1 Introduction

This chapter provides the reader with background information on the evolution within radar, AIS and IBS leading up to the aim and objectives for the thesis.

Chapter 2 Regulations and Literature Review

In chapter two the thesis discusses relevant research regulations and rules including a short explanation of AIS. The chapter refers to accidents reports and the collision statistics during the last decades. The education and officers training are presented.

Chapter 3 Research methods

Chapter three describes the quantitative and qualitative methods used, explaining the validity and reliability of the report achieved through the three different field tests.

The method of using 3 different approaches is described along with the limitations of the thesis.

Chapter 4 Findings

This chapter describes the field work, presenting and discussing the findings in the three individual areas.

Chapter 5 Conclusion

The conclusion brings a complete layout of the thesis, answering each of the three objectives.

Chapter 6 References

The references are displayed in Harvard style.

Chapter 7

Six appendices are listed at the end of the thesis.

2 Regulations and literature review

2.1 Introduction

During the last 10 years, navigators from the Royal Norwegian Navy have experienced the development away from paper charts and the development from stand alone navigational systems with radar as the only electronic aid to complex integrated systems (S. Nyhamn, Personal experience). The modernisation did not only promote safer and more effective navigation, but also presented certain implications that had to be dealt with (NNC, 2009).

Due to the complexity of the IBS and the introduction of ECDIS in the past years, the radar has received less attention within procedure development, education and training in the Norwegian Navy (NNC, 2012).

Radar has gone from being the sole means of control to one of many navigational tools within the IBS (ibid.). Although there is a general perception that radar is the most important electronic aid for anti collision and safe navigation, the focus of development, understanding and training has got competition from other electronic aids and a complex IBS and a more technology driven ship in general.

The choice of literature reflects and supports the research objectives.

In the RNoN there has not been any research investigating the utilisation of these aids for anti-collision. The studies within navigation in the Norwegian Navy have been discussed in two MSc's and one PhD; ECDIS vs ECS (Bøhn, 2011) , development of new anti-collision algorithms for radar (Grepne-Takle, 2011), and a PhD in the area of Human Machine Interface and design of bridge system (HMI) on FPBs (Røed, 2007).

In its research project 545, the Australian Maritime and Coastguard Agency (MCA) describes the problem when the human element is not considered when designing highly automated bridge systems (MCA, 2007).

None of these reports are directly applicable as a basis for this study, but underlines the technological evolution and the necessity to do research in this area of interest.

Mainly due to few units in the Navy there are few incidents described in empirical studies. The research on accidents from 1998-2005 (Gould et al., 2006) shows the performance shaping factors that can only partially be utilised for statistical purposes. This thesis reviews reports and statistics from civilian maritime agencies in Norway, United Kingdom, and Australia.

This research mainly focuses on technical elements; it is a fact that there is a thin line between physical technical elements and the more human related elements as Røed (2007) explores in his PhD. Even if this is technical research, it is natural also to draw attention to the rules and regulations.

2.2 Short description of AIS

When set up, AIS is a 100% automatic ship-ship and ship-shore information exchange system. It uses 2 Very high frequency (VHF) channels for data exchange and Channel 70 for automated administrative purposes. AIS broadcasts the ship’s position, speed, and navigational status at regular intervals. The information originates from the ship's navigational sensors.

All the users transmit on the same two frequencies and in order to organize the digital traffic, AIS utilises the transmission protocol, the Self Organizing Time Division Multiple Access, SOTDMA. All ships reserve a time slot in the future simultaneously with present message. Time synchronization is vital for the system to work, and the AIS receiver uses a GPS time from an internal receiver. If GPS is not available, the AIS will not work. The transmitted position of the ship is primarily sent from the official position sensor, which in most cases is GPS. The digital transmission is able to carry a lot of information but in order to not overload the system, the information is prioritised and organised. The most important data is transmitted more often than less important data. The data is divided in three groups; Static, Voyage Related, or Dynamic data.

“Static data” is fixed to the vessel, and is normally entered upon installation and broadcasted every 6 minute:

- Maritime Mobile Service Identity (MMSI), Ships name, Call sign, IMO number, Type of Vessel, Length and beam, location of Global Navigation Satellite System (GNSS) antenna, and height over keel.

“Voyage Related Data” is manually entered data at the voyage start, and kept up to date during underway. This is broadcasted every 6 minutes:

- Ship‘s static draught, destination, estimated time of arrival (ETA), type of ship, hazardous cargo and number of person on board.

“Dynamic data” is sensor data that changes with the ship motion. Depending on speed and the changing of heading, the interval can be from every 3 minutes (at anchor or less than 3 knots) to every 2 seconds (speed greater than 23 knots or speed between 14 and 23 knots and changing course).

- Ship’s position, time in Coordinated Universal Time (UTC), course over ground (COG), speed over ground (SOG), heading, Rate of Turn. Receiver Autonomous Integrity Monitoring (RAIM) is indicated.

The MMSI number is sent with every message to identify the sender even if it is categorised as “static data”. The system also has the possibility to send and receive text messages and has a built-in flexible message facility called AIS Binary Messages which allows development of the system in the future.

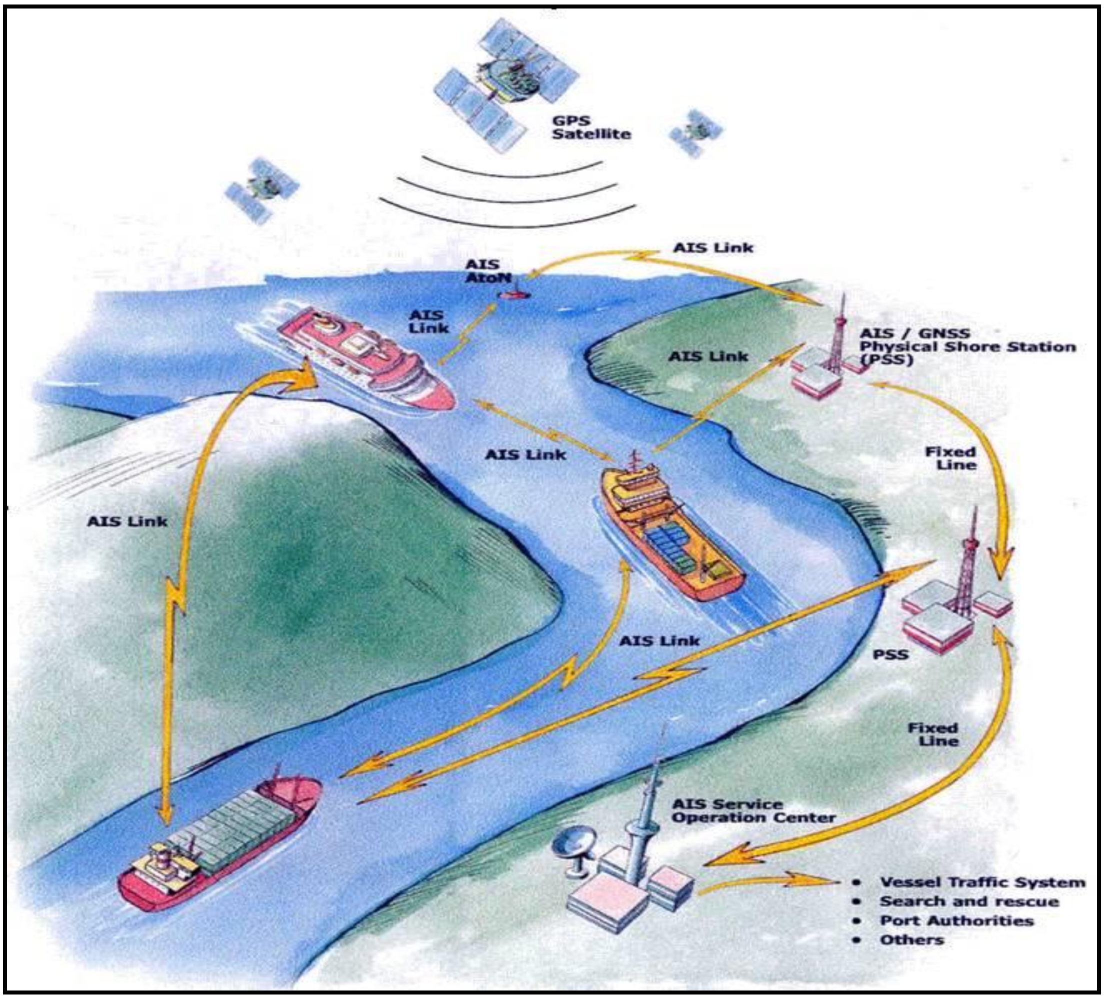

Figure 2-1: Overview of the AIS system (courtesy NNC)

Figure 2-1 explains the whole system in a nutshell. The AIS link has the ability to reach another ship that is not visual because VHF propagation is better than that of radar due to the longer wavelength. The signals do not suffer from distortion as does the radar (rain, sea clutter). The figure also reveals this complexity and that is has become more than an anti-collision aid. An example of that is the launching of AIS satellites to keep better control of traffic.

2.3 Relevant research in the area

The modern integrated radar in an IBS is very complex, having a variety of operational possibilities. In addition, the introduction of AIS has added more advantages, possibilities, and challenges.

"Get Your Head Out Of Your AIS" is an example of article printed in the *Windcheck Magazine* in 2012 that focuses on the pitfalls of modern equipment. The author asserts that use of AIS may contribute to the loss of situation awareness (SA), making the operator make wrong decisions (Weiss, 2012). The author of this article who claims that AIS is making it more dangerous than before AIS, contends that this should be expected shortly after the introduction of a new system or invention. However, this article is from 2012, 10 years after the IMO SOLAS Agreement that required that most vessels over 300GT on international voyages to install an AIS transceiver. This indicates that there is still some work to be done to achieve full benefit of the new systems as well as trust by the users.

The full potential of combining radar and AIS in an integrated bridge is yet to be fully researched. In "*Integrated Bridge Systems vol. 1 RADAR and AIS"* Dr. Norris describes AIS as being at its infancy, and that lessons are still being learnt contrary to the radar that has been developed over 60 years. Shortcomings and usefulness in radar have been fully understood and it is still the main electronic aid for anti-collision (Norris, 2008). Even if Norris' statement about AIS is from 2008, it still corresponds with the recent experiences from the RNoN. Nevertheless, the navy has experienced some improvement concerning AIS during the last years, especially regarding the willingness to change navigational status and voyage data i.e. destination and ETA.

The purpose of the AIS is to be found in IMO's Recommendation on Performance Standards for AIS (IMO, 1998), where IMO proclaims that AIS should: "improve the safety of navigation by assisting in the efficient navigation of ships." On the other hand, the same resolution also states the following two purposes:

1. AIS should be used in a ship-to-ship mode for collision avoidance
2. AIS should be a mean for littoral states to obtain information about a ship and its cargo and as a Vessel Traffic Services (VTS) tool, i.e. ship-to-shore (traffic management).

The IMO resolution does not make the main purpose very clear; people who do not work as navigators might easily believe that this is a handy system to keep track of ships for economic, efficiency or safety purposes. Developers might see this as an opportunity to evolve AIS to better fit surveillance purposes that might overload the system with even more information e.g. with binary messages (Porthin et al., 2010).

Collision avoidance is also a main task of the radar and the AIS making is clear that these two electronic aids must be used together. The combinations of these two aids imply some challenges that are thoroughly described by Norris (2008). The fundamental differences and their pros and cons are described in detail because it is absolutely essential for the understanding of the use of these aids by the navigators listed in Table 2-1. The table gives an overview of the strengths and weaknesses of radar and AIS technology with regards to safe navigation and extracting target information.

	Radar and AIS compared	
	Advantages	**Disadvantages**
Radar	• Does not basically rely on any 'off-ship' systems, such as GNSS or cooperative targets • Is naturally ship relative and sea stabilised[1] • Relatively difficult to jam or spoof	• Suffers from rain and sea clutter problems which can easily obscure important targets • Suffers from being a 'line-of sight' system not able to see round headlands and islands, etc • Does not always give a good indication of heading on which collision avoidance rules are based • Detection of changes in speed and direction of targets suffers from significant latency issues
AIS	• Gives position, SOG, COG, heading and other target information, in principle as accurately as they are known on the target vessel • Changes in such data are rapidly transmitted to observing vessels with far less latency than radar • Transmissions are less influenced by ground screening effects and therefore can get data from non line-of-sight targets	• Relies on target having a switched on AIS transponder • Relies on good installation and upkeep of target vessels' AIS system • Relies on both target and own ship having good knowledge of their own absolute positions. • Total failure if GNSS fails at a system

Table 2-1: Radar and AIS compared (Norris, 2013)

It is also fundamental that not all navigators are aware of these differences at a sufficient level. Radar is a ship based system of which the user has full control, as opposed to the AIS system where the user just receives data without knowledge of the quality. Even if it is an obvious statement that could be superfluous, the IMO resolution about guidelines for the use of AIS (IMO, 2001) asserts that "the accuracy of AIS information received is only as good as the accuracy of the AIS information transmitted." Hence, AIS should not be used as sole means of determining collision avoidance action. However, data from AIS is fast and accurate and if correct, the

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[1] Sea stabilization is a mode of display whereby own ship and all targets are referenced to the sea, using gyro heading and single axis log water speed inputs.

Ground stabilization is a mode of display whereby own ship and all targets are referenced to the ground, using ground track or set and drift inputs.

absolute best data to base the decision on, but since you can never be 100% sure it must be compared with the radar (Norris, 2008). Nevertheless, it is quite understandable that the navigators regard the AIS as the truth simply because it normally is. This means that levels of effective and relevant use of these aids are a function of education, training, and procedures.

Both systems provide closest point of approach (CPA), and time to the closest point of approach (TCPA) which constitutes the main information needed to evaluate a situation. In addition, both have other functions that are unique for each of them. AIS may provide visually displayed information to the user if the contact is turning, but radar can depict trails which show the past track of all visible targets as “smears” on the display as shown in Figure 2-2.

Figure 2-2: Trails and EBL (courtesy Dr Andy Norris)

Trails are useful in all radar modes and on recent, modern radars in the RNoN the most used mode is “north up fixed centre, true vector and trails” (NUP/FT) which is a mix of relative motion and true motion. It really is a relative motion because ship is not moving whereas land is moving. The smart effect in this mode, that makes the user believe it is true motion, is that the radar is not giving trail on echoes with the same speed and heading, but opposite compared to own ship i.e. they are not contacts but e.g. an island. In this way only targets will have trails, thus being easy to spot. There is, however, a condition that speed and heading input are very accurate. If not, the radar will interpret an island as a moving target. This mode is described in Radar performance standards, paragraph 5.20.1 (IMO, 2004).

Other important factors that confuse the navigators is what kind of speed input own and target ship have, as well as the use of true and relative vectors or electronic bearing line (EBL) as shown in Figure 2-2.

Heading and position input are also important, but not disputed as most ships use GPS and gyro input, which do not cause the same level of confusion. Both Norris (2008) and Kjerstad (2008) discuss this issue to a great extent. They both make it clear that the consequence of the choice of speed input must be understood because it can be crucial to situation awareness and to the decisions made to avoid a collision. Norris points it out this way:

> *"Radar and AIS data can only be used safely if there is a good understanding of true and relative vectors. A poor understanding can result in a major collision. Unfortunately, accidents caused by incorrect interpretation of vector information still occur"(Norris, 2008).*

The report from MAIB in the UK after the collision between MV *Spring Bok* and MV *Gas Arctic* underline the statement by Norris.

> *"The master selected true vectors and true trails for targets on the ARPA radar. This selection had the disadvantage of giving no relative information of a target, unless it was selected for display, which the master did not do."(MAIB, 2012)*

This topic is also described in the user manual for the SM 10 radar where the subject is highlighted, stating that it is of outmost importance that the operator is aware of the basic differences of true and relative presentation and stabilisation mode when assessing the traffic situation using vectors (Kongsberg, 2005). The users normally complain about the shortcomings of the manuals provided by the producers, but in this case they have gone beyond the normal level of user manuals and into a textbook mode.

The use of relative vectors is the best and easiest tool to discover if the target is on collision course or not. However, the deliberate toggling between true and relative vectors gives the best SA. EBL and optical bearing are also an easy solution that gives a good indication of collision danger.

The confusion of true and relative mode of radar is also discussed in the Kongsberg user manual (ibid) and by Norris (2008, p.70). Norris describes that there are three main independent ways of detecting and evaluating the risk of collision: visual, by radar or by AIS. The Norwegian Navy basically follows these principles, but is in general mostly focused on controlling the positioning of own ship and not anti-collision. The bridge manual for the coastal corvettes, the Skjold class, determines three different methods of controlling the position: visual, combined radar and visual and only radar (MTBTS, 2009). The fact that the whole manual is dedicated to ECDIS reflects the navy's centre of attention after the transition to paperless navigation. The manual, however, only describes radar in a restricted visibility scenario, not in anti-collision.

The IBS on the FPBs and the frigates are produced by Kongsberg Defence Systems. On the company web page the bridge is described as a "Tactical Bridge System that features an integrated solution designed to support the navigator, (Kongsberg, 2013)" but the system is based on the type approved[2] civilian bridge system from Kongsberg Maritime, which implies that the IBS meets most of the terms regulated by IMO.

It is also important to mention other functions that are designed to assist the operator in the process of situation awareness and avoiding collision. Two of them are "Fusion of targets" and "Automatic acquisition".

Fusion means that an AIS target and a radar target are identified to be one target based on certain criteria. The difference in position and speed should be less than a configurable limit, and both criteria need to be fulfilled to fuse the two sets of data into one target.

IMO is using the word "associated" if the criteria are met (Norris, 2008). This function can be an advantage because the screen will be de-cluttered as there is only one target vector displayed, thus adding to the SA. However, the danger is obvious if there in fact are two targets close together. Even if this tool is at hand, it does not mean that the operator can leave the system to itself. The system puts a lot of demands on the navigators to control the automated systems, evaluating whether the correct decisions have been made.

The automatic acquisition function is in a similar domain as fusion. On the basis of configured values set by the operator, the system will automatically track radar echoes, activating AIS targets.

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[2] "Type Approved" means that it has been tested to ensure compliance with the Performance Standards specified by IMO and the IEC

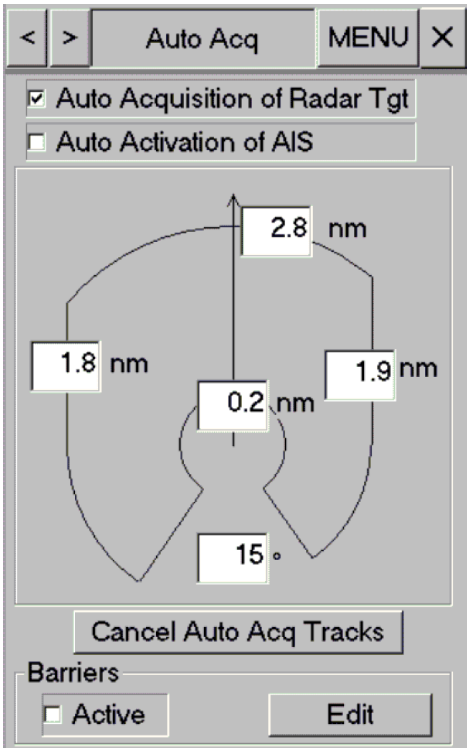

Figure 2-3: Auto acquisition menu on Kongsberg DataBridge10 radar

The Norwegian coast has an infinite number of rocks and islands. The challenge is that rocks and island are easily confused to be ship echoes, which is why automatic acquisition is not very much used in an inshore environment. However, there is a possibility to use barrier lines that could filter out the non-ship echoes. While the automatic acquisition area moves with the vessel, the barrier lines are geographically fixed limitations for the automatic target acquisition. Targets are not tracked behind the barrier lines. Barrier lines are stored for later use and can be activated and edited (Kongsberg, 2005).

The AIS system is based on exchanging digital data between users. Even if there is a limit to how much data can be included, and how fast it can be sent, a large amount of information is being communicated. This is in fact where it differs from radar, but AIS gives much needed information to the users. Some of this information, e.g. name of the ship, was often communicated by voice on the VHF prior to the AIS. We could assume that this would contribute positively to the navigators' SA. It definitely does, but there is always a down side. From 2004, the Norwegian Naval Centre (NNC) has gathered the experience after the introduction of ECDIS and IBS systems in the navy. One of the findings was that the navigators regularly found themselves in a state of information overload (NNC, 2006). In many cases, more available data was welcoming and interesting, but could lead to a delay in decision making, and in addition, the data was often interpreted as the truth without any critical evaluation.

The study of the development after the introduction of IBS also found that the new systems required more training as displayed in Figure 2-4. In the figure it is explained that until the introduction of IBS, the education and training were able to keep up with the need. However, after IBS, the need for education and training increased but was in fact reduced. The reduction had partly to do with lack of resources and partly to do with the belief that the new systems were easy to understand and learn (NNC, 2006).

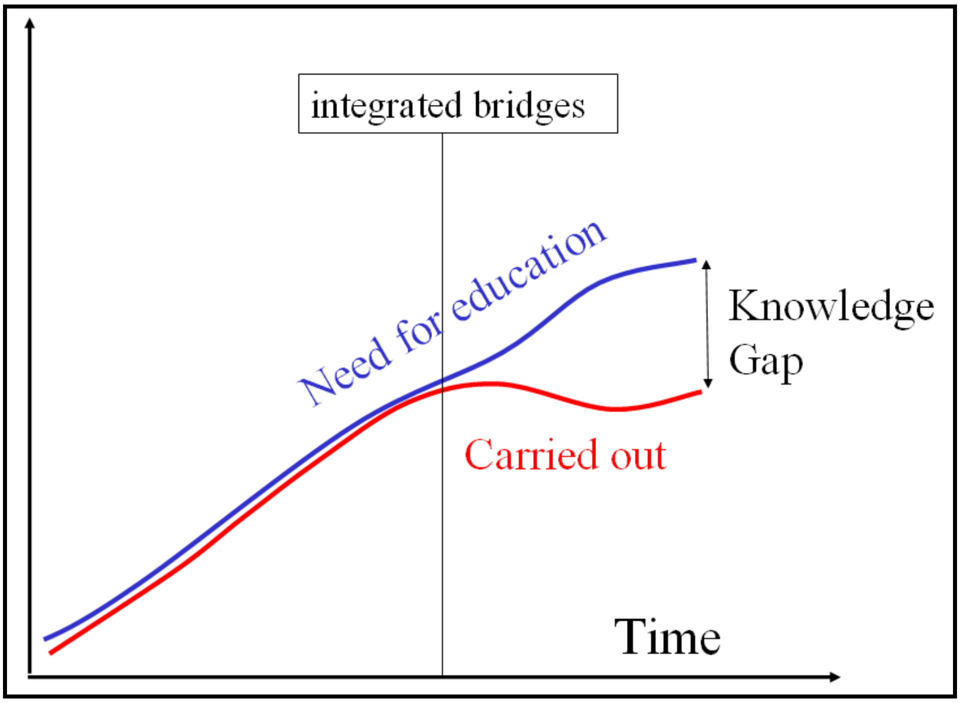

Figure 2-4: Complexity and education in integrated bridge systems (courtesy NNC)

"Keep it simple, stupid"[3] (KISS) was a design principle noted by the U.S. Navy in 1960. The U.S. Navy "Project KISS" of 1960, headed by Rear Admiral Paul D. Stroop, stated that most systems would work best if they were kept simple and not complex (Dalzell, 2009). In light of the last decades' evolution, it might be fair to say that the KISS principle has been abandoned in the new integrated bridges operating in a highly technological, sophisticated, and complex environment.

In 2013 NNC published a military publication, Navy Military Publication (translated), SMP 500. This publication is based on 10 years of experience, containing

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[3] The acronym has also been interpreted "Keep it simple, straightforward"

recommendations, explanations and regulations that are aimed to make it easier for the departments in charge of education and training and for the navigators themselves.

2.3.1 Investigations and statistics on collision

In 2011 NMD issued a report, Marine casualties 2000 – 2010 (NMD, 2010). Figure 2-5 displays the evolution of collisions within Norwegian waters from 2000 to 2010. Despite a positive trend until 2008, the two last years have revealed an increase in collisions. In 2010, 24 collisions involving 44 vessels were recorded.

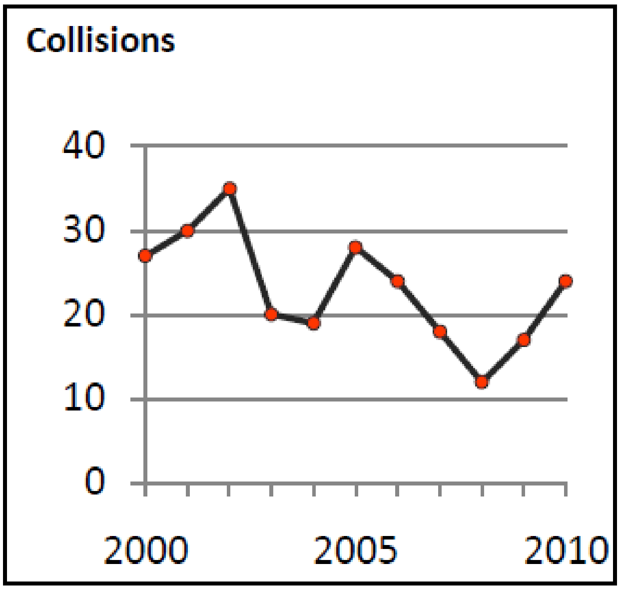

Figure 2-5: Numbers of collisions within Norwegian waters, 2000-2010. (Courtesy NMD)

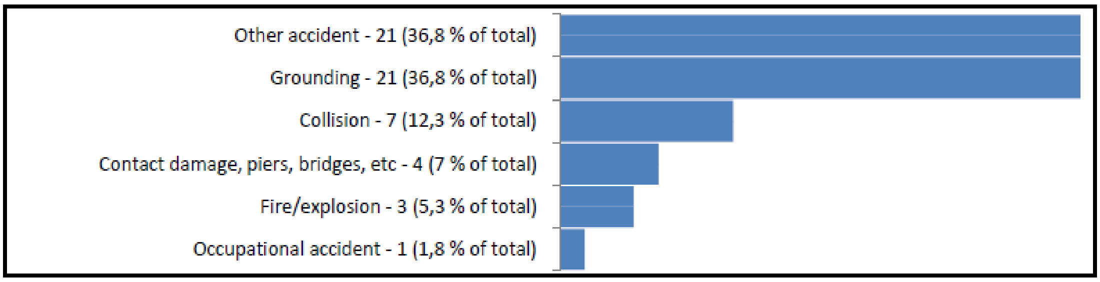

Figure 2-6: Near accidents in 2010 by type of accident. (Courtesy NMD)

As Figure 2-6 shows, there have also been 7 near collisions in 2010 (the record started in 2008). In the decade covered by the report, there have been 7 fatalities as a result of collisions. The report does not include statistics regarding the reason for the collisions because in recent years, instead of stating human or technical errors, explanatory models have been developed that emphasize an understanding of systems, taking into account various factors of the direct reasons. In general, the report lists recurring factors as failure to use the look-out, the distribution of tasks on board, administrative burdens, inattention, too little sleep or shift schedules that stretch over many weeks, inadequate communication, lack of maintenance, ergonomic solutions, etc.

For comparison, the report from The Marine Accident Investigation Branch (MAIB) in the United Kingdom analysed the use of radar. The most common contributory factors in all the collisions were poor lookout and poor use of radar. The report also determines that “a proper lookout is achieved in a number of ways, not only visually; radar, AIS, radio, and telephones all need to be monitored” (MAIB, 2004).

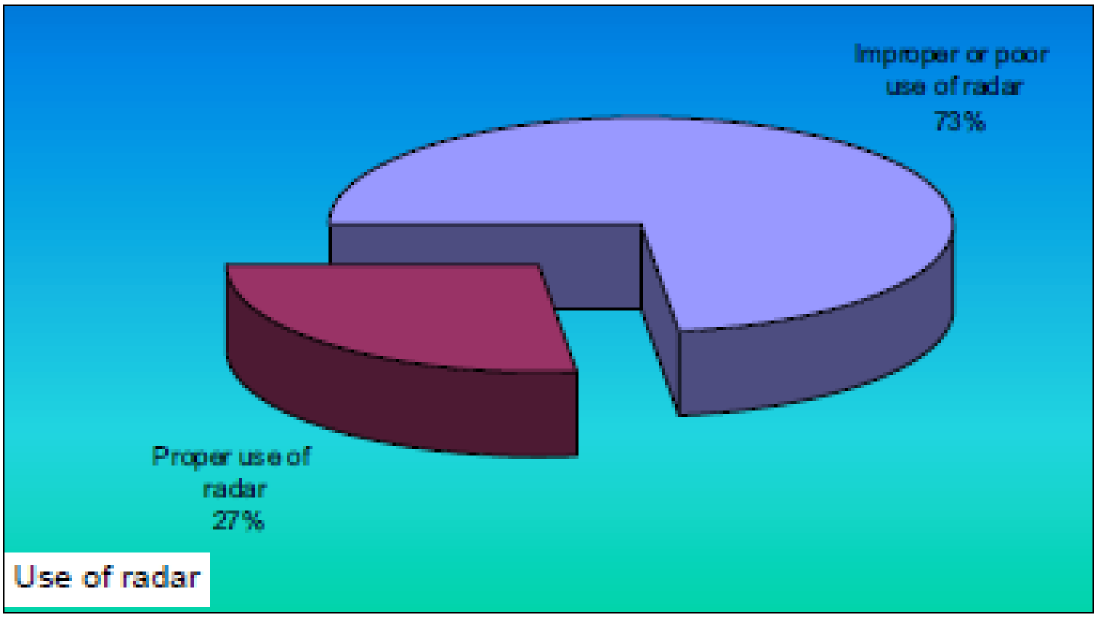

Figure 2-7: Use of radar, Vessels contravened Rules 7(b) or 7(c) in COLREG (Courtesy MAIB)

The same report also points out that 73% of the vessels involved in collision did not use the radar properly and potentially contravened COLREG 7(b) or 7(c) (IMO, 1972) which states (Figure 2-7):

> *Rule 7(b) – proper use shall be made of radar equipment fitted and operational, including long range scanning to obtain early warning of risk of collision and radar plotting or equivalent observation of detected objects.*
>
> *Rule 7(c) – Assumptions shall not be made on the basis of scanty information, especially scanty radar information.*

Looking into different individual accident reports from e.g. MAIB and Australian Transport Safety Bureau (ATSB), there are many examples emphasizing the aforementioned findings;

Although he could have displayed the target information on the radar display, he chose not to and the opportunity to visually monitor the target's data was not taken (MAIB, 2013).

The master selected true vectors and true trails for targets on the ARPA radar. This selection had the disadvantage of giving no relative information of a target, unless it was selected for display, which the master did not do (ibid.).

The Bridgemaster display was equipped with automatic acquisition and tracking, and guard zone facilities, but these were not used (MAIB, 2005).

There is little doubt that a correctly tuned radar and an appropriately setup AIS unit on board Global Supplier would have aided in avoiding the collision (ATSB, 2010)

All the reports clearly underline that there are challenges in the use of the modern aids to avoid collisions. Several of the reports also mention poor use of AIS, varying from not being used at all to not fully understanding the AIS system.

2.4 Regulations and rules

2.4.1 International regulations for preventing collisions at sea

The most important rules for avoiding collision are of course the International regulations for preventing collisions at sea from 1972, being implemented in 1977 (COLREG) with amendments (IMO, 1972).

The most relevant for the use of radar and AIS are in Part B Rules 5 (look-out), 7 (Risk of collision) and 19 (Conduct of vessels in restricted visibility) (Appendix A).

Rule 5 states that "there shall be a proper look-out by signal and hearing as well as by all available means to appraisal the situation and the risk of collision." AIS is not mentioned in the COLREG but it is agreed that the wording "by all available means" must include AIS (Norris, 2008, Patraiko, 2013).

According to the report (MAIB, 2004) 65% of the vessels involved in a collision contravened rule 5. A proper look-out is not only visual, but includes all electronic means that can help in assessing potential dangerous situations.

Rule 7 discusses how to determinate collision risk. Again, it declares that all available means shall be used. This rule indirectly indicates that there is a need to understand the limitations and possibilities of the equipment.

In cases where a current is affecting a ship, there is not a good indication of the heading on the radar, even if it is in a sea stabilised mode. In these cases, target heading from the AIS can make a good overview of the situation, thus giving the potential to follow rule 5.

Rule 7 c is relevant since it articulates the following: “Assumptions shall not be made on the basis of scanty information, especially scanty radar information.”

Received AIS data of which the operator has no control, must by itself be regarded as inadequate and unreliable data the same way as the rule states that you should not rely on insufficient radar data.

Rule 19 describes the conduct of vessels in restricted visibility. Radar was for a long time the only aid that would help in low visibility and, of course, not only concerning anti collision, but in general for safe navigation. On the other hand, AIS has added a dimension as it can deliver important information when there is poor visibility. However, AIS is most relevant as an aid to avoid collision, making it easier to comply with the instructions in rule 19.

AIS is not mentioned in the COLREG, in other words, it is important for the users to realise this, and one should rather use AIS as an extra aid to radar information.

2.4.2 Conventions and performance standards

New ships in RNoN like the Skjold class and the frigates fulfill the performance standards for IBS (IMO, 1996), Radar (IMO, 2004) and AIS (IMO, 1998).

However, due to specific military operational requirements, there are several dissimilarities with a civilian system.

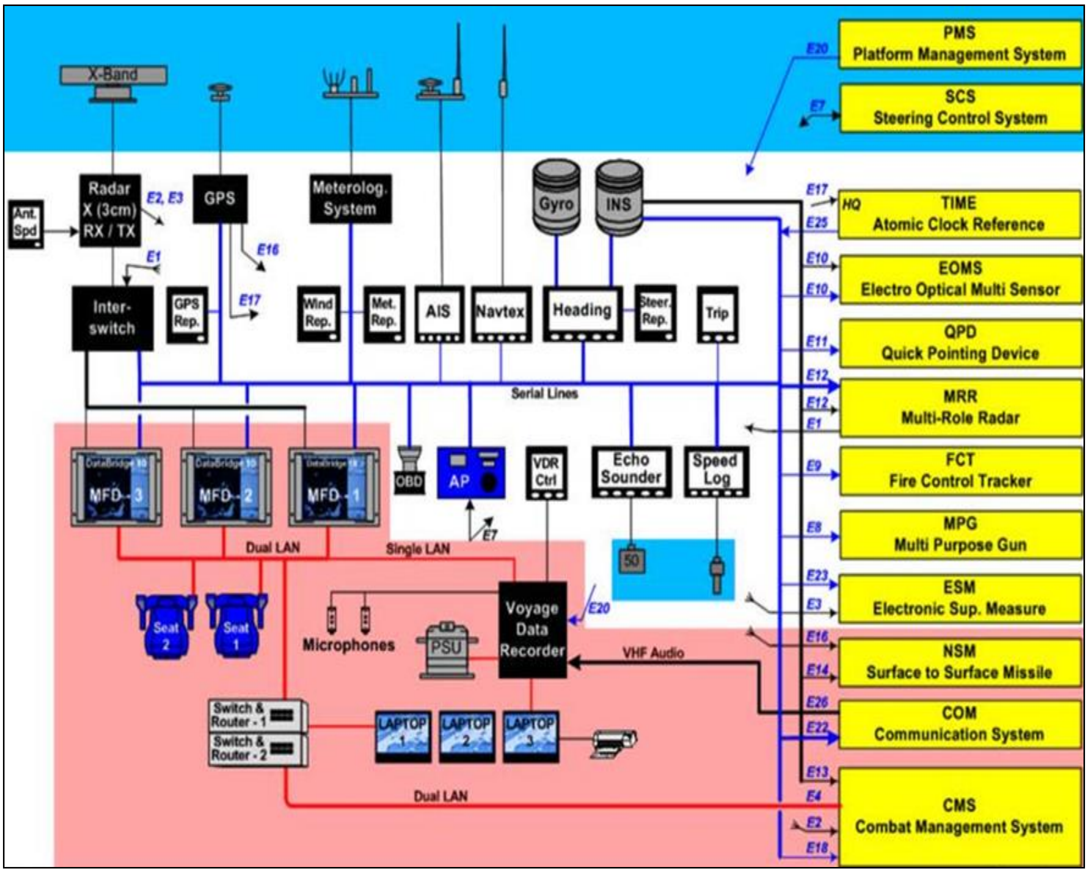

Figure 2-8: IBS on modern naval ships

In most cases features and functions are added, e.g. inertial navigational systems (INaS) which are included as sensors to the bridge and the weapon system. There is a complex level of integration with the operation room (see Figure 2-8), and several types of radars serving tactical purposes can be added in addition to the standard 3 and 9 GHz type.

The main goal when designing the new bridge system is to comply with as many civilian rules as possible. In IMO's SOLAS (Safety of Life at Sea) Convention chapter V; Safety of Navigation, warships are excepted to follow the rules but are encouraged to act in a consistent manner, as reasonable and practicable as possible (IMO, 2002). Chapter V, regulation 19, states that ships above 300 gross ton built after 1 July 2002 must have an electronic plotting aid, or other means, to plot electronically the range and bearing of targets to determine collision risk (ibid, Chapter V – 1/7/02 paragraph 2.5.5).

For ships of 500 gross tonnages and upwards, the convention also demands an automatic tracking aid for the automatic plotting of targets to determine the collision risk. In addition, all vessels above 500 GT (300GT if internationally trading) must be fitted with AIS.

The variable parameters are usually tonnage of the ships, passenger or cargo ship and if they are engaged on international voyages or not. Table 2-2 from "Revised performance standards for radar equipment" gives an overview of requirement to which SOLAS applies (IMO, 2004).

Size of ship/craft	<500 gt	500 gt to <10,000 gt and HSC<10,000 gt	All ships/craft =10,000 gt
Minimum operational display area diameter	180 mm	250 mm	320 mm
Minimum display area	195 x 195 mm	270 x 270 mm	340 x 340 mm
Auto acquisition of targets	-	-	Yes
Minimum ***acquired*** radar target capacity	20	30	40
Minimum ***activated*** AIS target capacity	20	30	40
Minimum ***sleeping*** AIS target capacity	100	150	200
Trial Manoeuvre	-	-	Yes

Table 2-2: Differences in the performance requirements for various sizes/categories of ship/craft to which SOLAS applies (IMO, 2004)

In 2008 the radar performance standard was amended to include the display of AIS as an overlay on radar and radar/AIS association capabilities to reduce display 'clutter'.

The standard also depicts a comprehensive description of requirements for a target tracking (TT[4]), Acquisition, AIS and radar target data in paragraphs 5.25 to 5.28 (IMO, 2004).

The convention also gives the regulation for ships that have to be fitted with AIS. These are all detailed rules about radar and AIS, but the facts are that most of the modern ships have installed AIS as they have experienced the benefit. Nearly all modern radars have included tracking and plotting capability. Even leisure craft radars may have a form of automatic plotting functionality. It is not possible, for example, to purchase a Kongsberg system without all these features.

For comparison, all ships in the Norwegian navy are equipped with a complete set of these navigational aids and functions independent of tonnage.

2.4.3 International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)

The 1978 STCW Convention was the first to establish basic requirements on training, certification and watchkeeping for seafarers on an international level.

The STCW has been amended twice, in 1995 (in force 1997) and in 2010 (in force 2012) to bring it up to date. Part A of STCW 95 is mandatory, while part B is

[4] TT has now superseded the acronym ARPA which is not used in the latest 2004 IMO document, but is still used in IMO training documents.

recommended. NMA has ratified the code, and in 2012 issued updated requirements stating the required level of knowledge that is mandatory to reach during the maritime education. For deck officer education, Chapter II; "Master and deck department" describes the overall requirements relevant for this thesis. As a result, the NMA has issued requirements for AIS and ECDIS for the maritime education institutions to comply with (NMA, 2013). The new requirements for AIS and ECDIS are well formulated and are up to date, having been included in the education and training in RNoN for all navigators in the Norwegian navy.

One aim in the AIS requirement is formulated the following way (translated from Norwegian):

> *"AIS Information is interpreted and analyzed properly taking into account the equipment's limitations, other systems/sensors and the prevailing circumstances and conditions" (ibid)*

To be able to apply to this requirement after the formal education it is vital to continue the familiarisation and training on board own ship and maintain the knowledge regularity.

2.5 An overview of the education and training in the RNoN

Lack of knowledge and proper training are repeated numerous times in accidents reports. All the students training to be a navigators at the Royal Norwegian Naval Academy (RNoNA) receive full theoretical education in accordance with "Standard of Training, Certification and Watchkeeping" (STCW 95), up to the highest level of deck officer certificate. The implementation of the last amendment from 2012 "the Manilla amendment" is an ongoing activity at the NNC. In addition to this theoretical education, the education accommodates the requirement set by the RNoN. These requirements are adding elements that are not mandatory by IMO through STCW 95. Figure 2-9 visually describes that the education includes all the requirements from IMO as well as the extra requirements that the navy and coastguard have required.

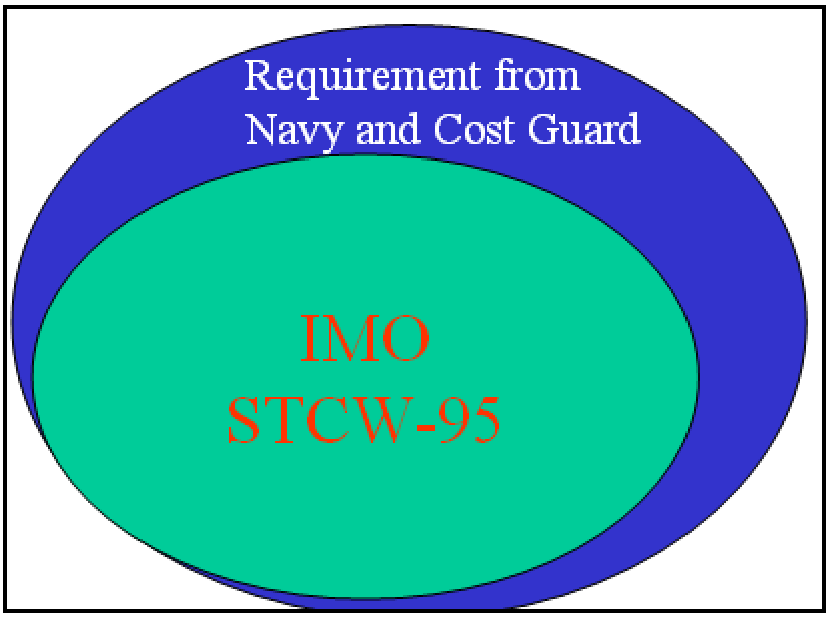

Figure 2-9: Illustration of the education covering both IMO and own needs.

The most important and time demanding activity for the students is the live navigation on the two training ships specially made for the purpose. The ships are only 50 feet but still have a full IBS and can do speed up to 43 knots (Appendix B). This navigation practise for students still at the academy drastically reduces the time needed to train navigation at the operational units.

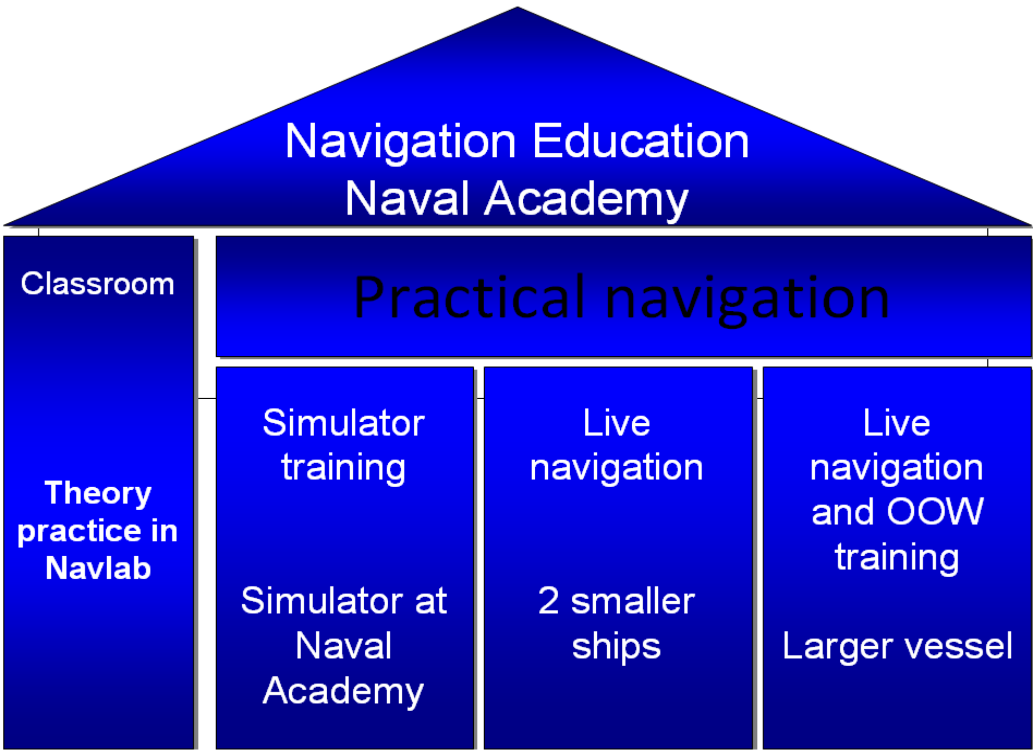

Figure 2-10: Theoretical and practical navigation education at the Naval Academy (courtesy NNC)

The overview in Figure 2-10 illustrates the students live and simulator experience before they start their operational career on board. During the studies at the naval academy, the future navigators also complete the IMO ECDIS Model Course nr 1.27 and AIS Operator Course, IMO model course nr 1.34. The automatic radar plotting aid (ARPA)[5] module is included in the STCW education. However, this only gives them a kick start on the path to a fully qualified Officer of the watch (OOW). The responsibility for this "on the job training" belongs to the operational ships and the training centres for each type of ship. This training is absolutely essential as it is important that users are familiar with the bridge system as also described in Norris (2008). IMO has underlined this aspect since familiarisation is a requirement of the STCW and the ISM.

In the magazine, *Navigare* issued by NMD in 2007, the director of the NMD, Rune Teisrud, addresses the topic as a reaction to a major accident within Norwegian littoral waters. He is worried about the increasing numbers of accidents. The article makes a point of the connection between causes of the accidents and the navigators'

[5] The abbreviation ARPA has been replaced by TT in the radar performance standard but is still used in the IMO training documents.

incompetence. When he articulated ”appropriate certificates are not enough” (Teisrud, 2007), this was coinciding with the Navy’s experiences which at the time heightened the focus of this question. The RNoN has thus recognised that the certificates in and of themselves will not constitute sufficient knowledge for the navigator. Perhaps the most important part of the navigator’s path to becoming an OOW starts after graduation from the academy.

The STCW 95 code, part A Chapter VIII describes in paragraph 36 the requirement for the navigators to be thoroughly familiar with the use of all electronic navigational aids, including their capabilities and limitations. This requirement points out the essence and the conditions that should be met in order to utilise the different navigational aids to their maximum extent. It is, however, recognised that this has become increasingly challenging on a par with the technological evolution.

In most cases the training to become an OOW is described, following a planned process. However, there is a challenge to make it more systematic and quality assured for all navigators from start to finish of the training period. In 2010 Frode Røte analysed how the training towards OOW was executed on the Fridtjof Nansen class frigate. He concluded that there were too many pedagogical differences from ship to ship, and that the training processes were too random. The students requested more alignment in the learning process (Røte, 2010).

2.6 Summery and emerging issues

There seems to be a clear trend that the development of new functions and more adjustment possibilities on radar, as well as the implementation of the AIS system, are not automatically appreciated and utilised by the operators. There are probable several possible reasons for this. Are the navigators in the RNoN aware of this, and do they make the most out of their equipment, or are they overwhelmed and/or not properly trained? Do they use the traditional “easy” aids as relative vectors and optical bearing to asses a situation or are they studying the data delivered by the computer system?

The RNoN uses a lot of resources on education and training, but after the technical “revolution” in navigation coinciding with reductions in activities reducing “on the job training,” there is a clear question if the operators are properly educated to handle the equipment in a sufficient manner. It is also a fact that accidents still happen and even though an important factor is human error, it is much more interesting to look at why there still are so many human errors when the aids are getting better and better, or are they?

3 Research method

The thesis applies both qualitative and quantitative methods. This has made it possible to compare the quantitative data with the qualitative observations. In their book, *Forskningsmetoder for økonomisk-administrative fag (transl. Research methods for business and administration)* Johannessen et al. explain the two methods as two different directions, emphasising that they may very well be used together and that they must not be assumed to be contradictory to each other (Johannessen et al., 2004). During the research this proved correct as this made it possible to discover possible connecting threads. The quantitative part provides a measurable data set whereas the qualitative data adds the understanding of why things or processes occur.

The method used to achieve relevant data was to do observations from three different angles and thus the field work was divided into three parts;

- Live observation on board the Skjold class
- Observations on simulator models for the Skjold class, the Fridtjof Nansen class, and for a corvette type (simulator model) ships
- Evaluation of knowledge through questionnaire interviews

The live sailing was a 600 nm transit inshore Norway coastline both in light and dark conditions and at varying weather conditions. The navigators' experience ranged from 1- 8 years. Obviously, the positive is that the observations are from live operations, but the disadvantage is that it is not possible to create incidents.

In the simulator two different areas and scenarios were designed to achieve as many relevant responses as possible. As opposed to live sailing, the simulator itself may affect the behavior of the officers to a certain degree. However, since the simulator is very realistic and familiar to the officers, the observations carried out are considered relevant and of high value.

Within the limitations of the questions, the questionnaire measured the knowledge of the operators regarding the understanding and use of radar and AIS at two levels of technical degrees of difficulty.

On board the Skjold class and in the simulator the main focus was to observe activity within the categories listed in Table 3-1.

<table>
<tr><th>Radar</th><th>AIS</th><th>Radar and AIS</th></tr>
<tr>
<td rowspan="3">• True or relative vectors
• Use of EBL
• Use of trails
• Time of target detection
• Search for targets
• Adjustment of radar: range, clutter, pulse length</td>
<td rowspan="3">• Target activated or sleeping
• Use of automatic activation
• Information reading
• Discovery of targets without AIS</td>
<td>• Procedure before departure
• Collision alarm
• Comparison of AIS track with radar track
• Use of automatic acquisition
• Use of target fusion
• Use of communication</td>
</tr>
<tr><td>Other</td></tr>
<tr><td>• Use of look-out
• Use of visual aids
• Use of OBD (Figure 3-1)</td></tr>
</table>

Table 3-1: List of possible observation elements that is related to objective 1

Figure 3-1: Optical Bearing Device (OBD) integrated in IBS (courtesy NNC)

The elements in Table 3-1 are all possible observations that are associated with the first objective:

> *"Identify and examine* the use of AIS and radar in anti-collision by live observations and simulated tests."

The second objective

> *"Explore* the knowledge of radar and AIS use relevant for anti-collision"

has been analysed to measure the level of radar and AIS knowledge that the navigators possess.

Based on the outcome of the two first objectives, the third objective

> *"Formulate* recommendations on the education and training within radar and AIS"

will indicate a possible need to change the training and procedures.

The method of doing observations on a naval ship on operational duty was challenging and timely both in regards to planning as well as the execution of the tasks. However, live observations deliver relevant and state of the art data. Even if the actual sailing was carried out in a few days, much work had to be prepared before the actual sailing occurred. The simulator scenarios were somewhat easier to set up but still it was a challenge to coordinate all the teams and all the scenarios. Several assistants contributed to a smooth and controlled two days of testing. It was important to do the questionnaire after the live sailing and the simulator tests, to ensure that the candidates were not affected by the aim of the research.

The data from live sailing was only the written observation as no recordings or pictures were allowed. In the simulator, however, the data was gathered by means of written observations and by video.

3.1.1 Reliability and validity

A high level of reliability and validity has been important for the process. Validity is how well the findings, measurement and conclusion correspond to the real world. The word "valid" is derived from the Latin, *validus*, meaning strong. Due to variety of the three different tests, there is a strong and solid connection between the thesis and the reality. It can further be explained by the question "Does the research actually measure what it claims to measure?" (Johannessen et al., 2004).

Reliability describes how trustworthy and reliable the data is. It is connected to the data in the research? Which method is used for collection? Which data is used and how is it used? (ibid.). This thesis employs three different approaches: questionnaire, live observation and simulator tests. For the quantitative part a questionnaire was used (Appendix C and D). 19 officers representing approximate 20% of the total navigators in the RNoN were interviewed. They had experience from 0 to 8 years, but from only two different types of ships. However, all were trained on a modern IBS which was important for the thesis. The 19 officers represent approx 35%-40% of the officers in the navy with IBS training.

The live tests have good validity as navigators are observed during real navigation. Nevertheless, with live observation the value depended on relevant incidents to happen. Hence, the number of incidents might not be as large as one would have hoped for. On the other hand, the data appeared reliable due to real observation during real operations. The live observation might also have a weakness being observed on board only one ship. However, there were different navigators who navigated over a long period of time, and the fact that all the Skjold vessels have the same operational tasks, operating in a similar manner can be seen to deliver a relatively acceptable solution. This considered, the collected data should also represent the real world and be of good validity.

The questionnaire was presented as interviews with model answers that gave pre-planned scores. All the officers were thus equally treated and there was very low degree of misunderstandings. This approach added good reliability to the research.

In the simulator there was ample opportunity to test similar scenarios on different teams. The same scenario was repeated several times, making the findings produce high reliability. The advantages of using simulators are that it was possible to create as many scenarios as deemed necessary. In addition, it was possible to make sure that the targets ships behaved in a way that created the desired anti-collision response.

According to Johannessen et al. (2004), observations can be divided in, among others, structured and unstructured observations. The thesis mainly aimed for a structured observation using a track sheet that focused on the observations that were relevant to anti-collision activity (Appendix E). Nevertheless, in a complex scenario it is not always easy to foresee what will happen next when underway e.g. changing speed can inflict the next happening. Consequently, it turned out to be a combination of structured and unstructured data. This made it particularly important to sum up all the observations shortly after the tests (Johannessen et al., 2004). All the findings were organised within 14 days.

3.2 Limitations

The apparent limitation in the research is that only military ships are investigated. On the other hand, the IBSs in this research are modern and very similar to civilian bridge systems.

The ships in this research are capable of sailing in open sea where navigators use slightly different procedures compared to closed waters procedures. Meanwhile, the different scenarios are all in littoral waters, giving a better outcome as the navigation in these waters is much more challenging and thus more relevant for exploration of the thesis problem.

Value has been added when investigating ships that had the possibility of sailing at high speed; this is an increase in the level of difficulty. On a naval ship, speed is a force multiplier[6] which the navigators have to master.

This thesis did not look at navigation in a simulated wartime or conflict scenario which would result in a much more dynamic and unpredictable navigation, possibly reducing the value of this study.

The thesis focuses primarily on the technical use of radar, AIS and other anti-collision aids, not reflecting on the psychological factors, yet recognising that these factors have become increasingly interesting when evaluating an IBS navigational team.

[6] In military usage, a force multiplier refers to an attribute or a combination of attributes which makes a given force more effective than that same force would be without it.

4 Findings

4.1 Introduction to the live observations

All the observations were registered on board the Skjold Class high speed craft (Appendix F). The only task carried out by the ship was high speed inshore navigation which varied from open to very narrow waters. The team navigated unaware of the detailed purpose of the observations which was to observe the navigators’ use of radar and AIS as aids in preventing and avoiding collision. No specific scenarios were initialised.

The testing was conducted during the summer, and the area covered was Narvik to Bergen, a distanced of approx 600 nautical miles, covered over ca 36 hours.

The ship navigated both at daytime and at night time, but in northern Norway it did not turn dark due to the midnight sun. Navigation did occur in the dark; however, this took place on the last night in the area north of Bergen which is also the most demanding sailing area. As the weather also got worse in this area it became natural to rely more on radar and AIS.

The observations are divided into 5 parts and are in chronological order.

First leg (part 1, 2 and 3) without darkness was from Narvik area to Trondheim area. Second leg (part 4 and 5) was from Trondheim inshore leads to Bergen.

The detailed routes of navigation are restricted due to military regulations, and cannot be disclosed. This will, however, not reduce the output of the thesis.
During the observations described in this thesis, there were never any dangerous or close-to-dangerous situations.

4.1.1 Organisation of the Skjold class IBS

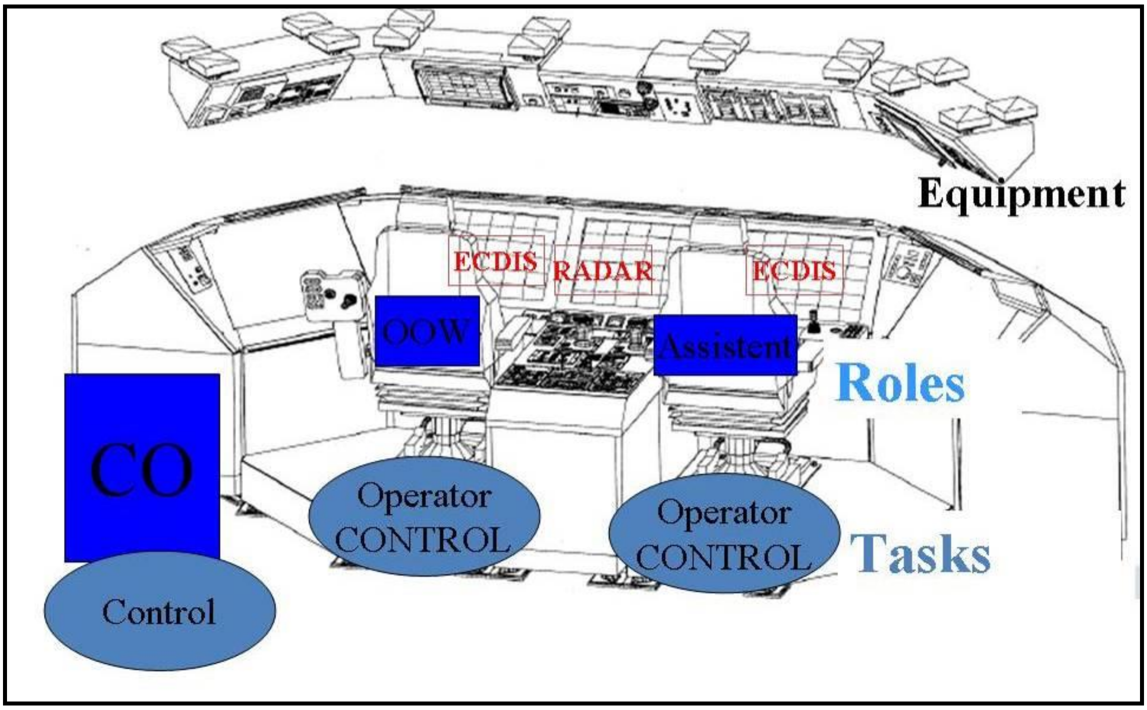

Figure 4-1: The organisation of a Skjold class bridge

As shown in Figure 4-1 the Skjold bridge is designed for two operators (OOW and the assistant) but has also been specified as a one man bridge. However, in the field tests, the conditions demanded that always two navigators were present. These two were constantly evaluating which tasks to prioritise, dividing the tasks between them to be able to perform safe and efficient navigation. The screens are multi functional and can be configured to show ECDIS, radar or conning. This gives flexibility, but some functions can only be operated by the OOW or the assistant. All officers in the role of assistant had navigation education, some of them were trainees and occasionally they were qualified OOW. The commanding officer (CO) would at times overlook the navigation.

4.1.2 Live sailing, part 1. Through open waters in the Vestfjord,

Even if the checklist for departure includes control of the radar, it was not tested and adjusted prior to departure. This was probably due to the good weather.

In the first part, the navigators practised “radar control” in narrow waters which means that restricted visibility is simulated. The speed was 42 knots and the radar was mainly used for positioning of own ship. Several targets appeared along the route but no specific anti-collision incident occurred in this part. However, the general experiences were:

- When the radar was turned on, it was not immediately adjusted for optimal picture quality. The visibility was very good with zero wave height, i.e. no effort was made to optimise the radar picture even if the purpose was to train control by radar. Nevertheless, the picture quality was sufficient to discover the upcoming targets and positioning of the ship
- Parallel indexing (PI) was extensively used for controlling the ships position. Gain and clutter control was adjusted to optimise for PI navigation which took most of the focus, thus searching for other ships did not have highest priority
- The radar mode was “north up fixed centre, true vector and trails” (NUP/FT) which is the most used mode
- Log input was “ground” and “trails” were off all the time. It did not seem that these settings were deliberately set for a reason
- Several targets both with and without AIS were discovered. Most were too far away to be a potential navigation danger but one vessel came close and was avoided by changing course. No electronic calculations were made and neither relative vectors nor Electronic Bearing line (EBL) facilities were used

In open waters progressing at high speed, it seemed very convenient, practical and fast to avoid a target by changing heading which is in according with COLREG Rule 8C and described by Cockcroft and Lameijer in their book, Collision avoidance rules (2011). Following this principle definitely worked, but did not add much learning experience regarding use of other anti-collisions aids.

4.1.3 Live sailing, part 2. Bodoe area north in open to narrow waters

In this part the vessel entered narrow waters and the control was changed to “visual control” but the speed was still 42 knots. The visibility was very good making it easy to visually detect two contacts on port bow. As they were both estimated to be of no danger, they were not tracked and the AIS information was of no of interest. The AIS targets were left in “sleeping” mode.

An AIS advantage over radar is that a target behind an island can be detected and in this case an AIS contact that turned out to be a fast ferry that was displayed on the ECDIS and the radar quite early (see Figure 4-2). The operators had the opportunity to investigate this target by reading the relevant AIS data. With a potential relative speed of about 70 knots there was a risk for close encounter after turning starboard. However, the AIS target was never activated, and it turned out to have low speed, increasing speed after being visually detected at the same time as own ship speed was reduced.

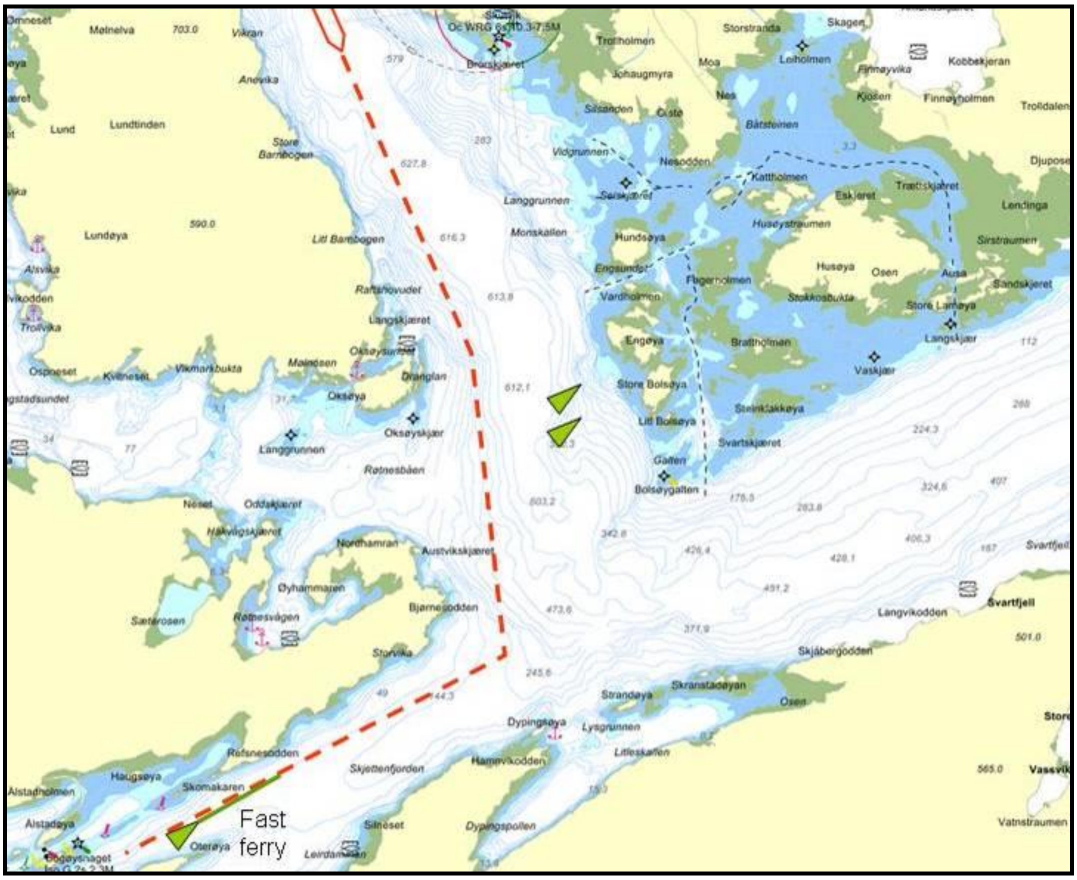

Figure 4-2: **Part 2, entering inshore**

4.1.4 Live sailing, part 3. Area Bodoe north in very narrow waters

In part 3 the navigators were practising high speed navigation in very narrow waters with focus on optical control of both positioning of own ship and detecting other ships. In this period there was no effort made to search for AIS or radar contacts. Optical control seemed to be the best way to do this kind of navigation and the two navigators used all their focus on positioning based on visual observation. The area was cluttered with several islands that made it difficult to single out target echoes on the radar; hence the radar did not provide any easy target indication. Nevertheless, the AIS would be useful to spot potential targets along the route, bearing in mind that not all vessels within these narrow waters are obliged to carry AIS.

4.1.5 Live sailing, part 4. From Bodoe and southwards in open and narrow waters.

The conditions were very similar to part 1 regarding high speed, daylight conditions, and calm sea. At departure, again the radar was not checked. The first part of the navigation was carried out with “visual control”. When own ship approached narrow waters, preparing two significant turns, two vessels were detected (see Figure 4-3), one visual and one on AIS. Both targets were a potential danger, generating a lot of focus from both navigators.

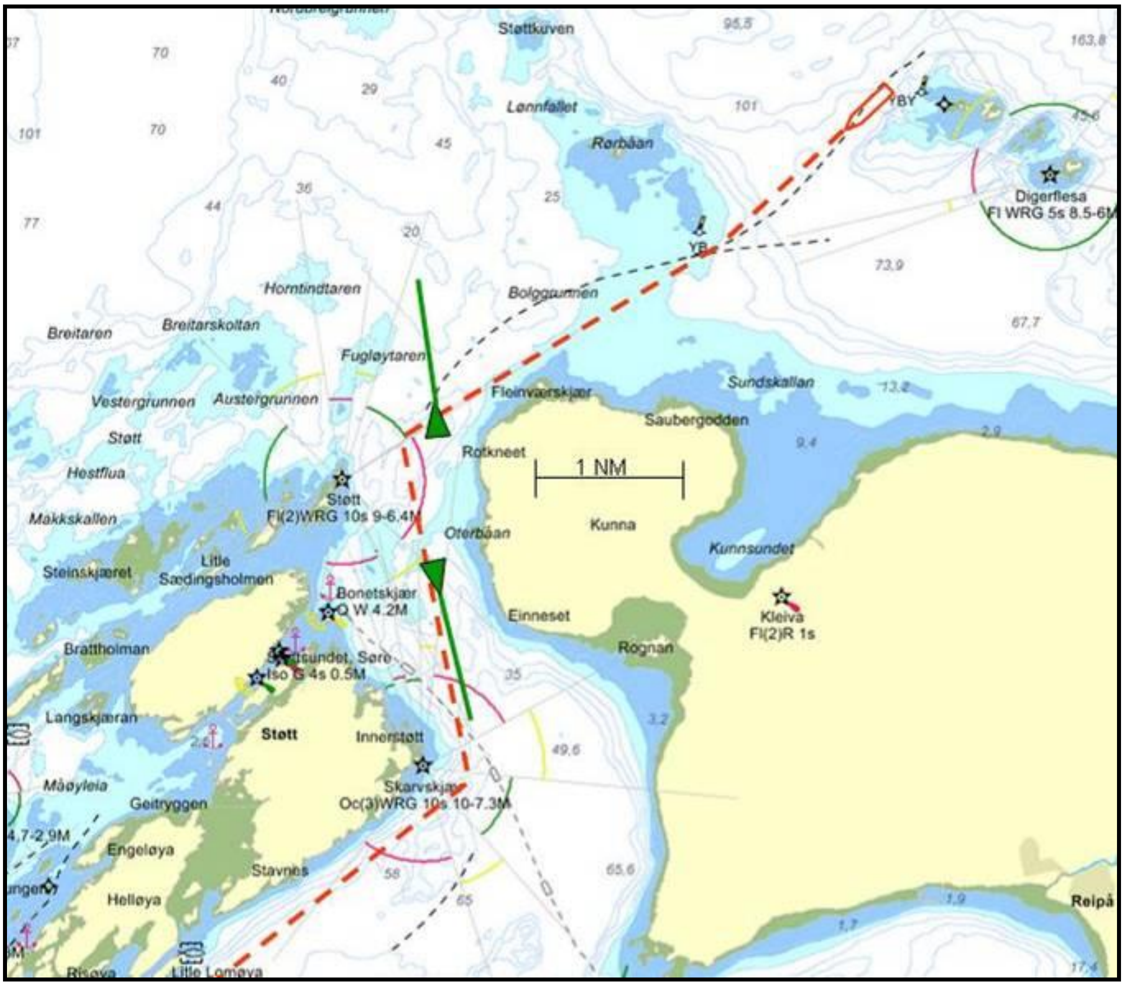

Figure 4-3: **Part 4, passing and overtaking of contacts**

Both contacts (large fishing vessels) transmitted AIS data, but the navigators did not activate the AIS target, thus no further information was gained. However, the collision alarm worked as it is independent of AIS targets being activated or not, but due to several alterations of own ship course, the alarm criteria were constantly changing, giving the alarm little value.

Relative vectors were not used, and the deviations were based on visual observations which resulted in several, perhaps unnecessary, deviations.

In addition to sorting out how to pass and overtake these two vessels, the OOW had a lot to do with adjusting the raid control (adjusting the air pressure that lifts the vessel) and communication with the engine room. In other words, at this point the OOW's workload was quite extensive, simultaneously having to keep up with the ECDIS picture.

The high speed on own ship made the overtaking of ships a near constant activity, but at the same time challenging as there usually was not much time to decide on the best way to overtake. In spite of that, the contacts were passed in high speed in a safe and controlled manner as depicted by the COLREG Rule nr 8C. An alteration in heading will normally be more effective than a change of speed to avoid close quarters which is what Cockcroft and Lameijer describes in his guide to the COLREG (2011). The Skjold class followed this recommendation at this incidents and it turned out to be the most used method to avoid traffic. Nevertheless, no electronic aids were used not even for training purposes.

4.1.6 Live sailing, part 5. In area Aalesund, narrow waters, in darkness with restricted visibility

The main lead north of Aalesund is an area with alternating narrow and open waters. Rain and darkness gave limited visibility of about 1-3nm and the speed was 20 knots. The control mode was "combined radar and visual".

As own ship passed the narrow "Lepsoeyrev" (see Figure 4-4), a contact was detected further south. The target was assessed as a potential danger, and the process of how to pass it started. Own ship seamed to have right of way but after a while it looked as if the contact intended to sail north to the Vigra fjord. Based on that, the navigators decided to turn port to solve the situation. It looked as the contact was unsure about our ship's intentions as it altered course two or three times.

Even if the visibility was so low that only the target's navigational lights were visible, the navigators did not utilise radar or AIS to their full extent. The AIS target was never activated and the data never read, nor was the target contacted on VHF communication. The radar operator adjusted the gain and clutter to achieve the best radar picture and the contact was tracked, but the decisions were mainly made after a visual evaluation. Dealing with this contact took all navigators' attention and no effort was made to search ahead for possible upcoming new targets. As the speed was 20 knots there was time to utilise the electronic information to a greater extent in addition to the visual observations carried out. The contact was passed in a safe manner and there was no danger at any time.

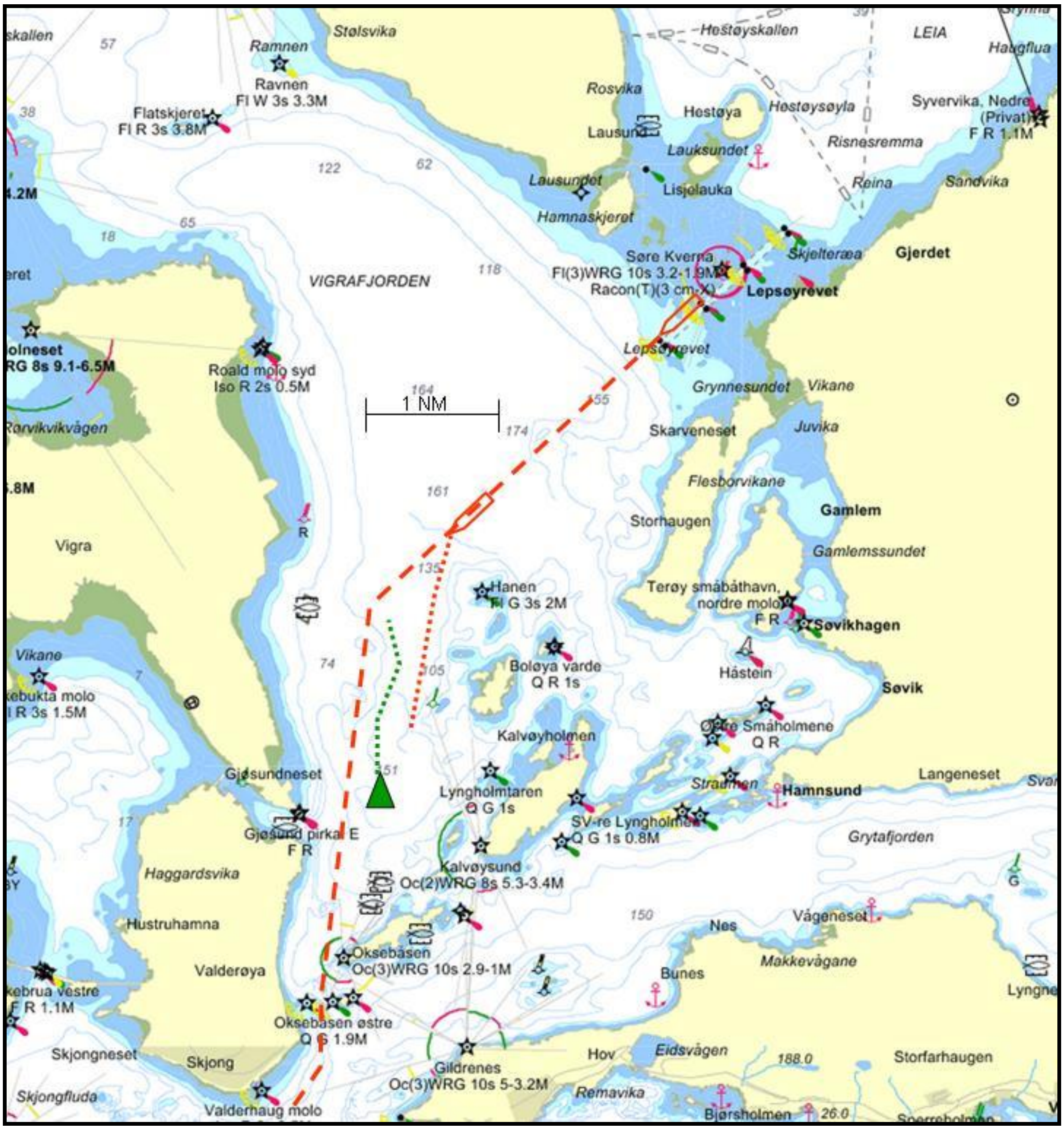

Figure 4-4: Part 5, passing of a target in darkness and at low visibility

4.1.7 Live sailing, summary of observations

The aim of this transit was to train the navigators in different control modes and level of difficulty. Their focus was to train control of the navigation by either visual, radar or combined radar and visual as described in their manual for the bridge (MTBTS, 2009).

In addition, the training element to advance with the highest speed possible is very often included. In general, the navigation was carried out in a very safe and controlled way.

When the control mode was "combined radar and visual control," the main focus was on visual evaluation of contacts detected on radar and/or AIS. None of the AIS targets were manually or automatically activated. There was no attempt to use AIS data to achieve more information, which would predict contact movements. All decisions to avoid collision were made after visual detection. The method of utilising speed and the ability to accelerate and de-accelerate very fast is generally very effective although no experience with other electronic aids is gained by the use of this method. Compared with the visual information, radar and AIS had definitely lower priority as information sources.

High speed combined with narrow waters was a demanding task for the two navigators and they were thus forced to constantly prioritise their work. Operating the functions via the menu system was time demanding, and when the functions on radar or ECDIS were needed, the operator had to focus solely on that task. When a navigator had to do such a task, he informed the other by stating “looking down.” Still, the operator looking down rarely used the time to search for AIS contacts.

There is no stated procedure to make sure that the settings of the radar are optimal. Instead the operators were adjusting the radar on a “need to do” basis. Trails were off all the time, relative vectors were not used, and the criteria for the collision alarm were never changed, although the alarm was detected and acted upon.

Part 4 and 5 included both navigation in 42 knots in daylight and 20 knots in the dark. In both cases the navigators focused mostly on visual contacts evaluation, but also showed that they used the radar to find radar tracks. However, even in the dark the targets were seldom activated, and data was rarely read before they made a decision to maneuver.

Tracking and AIS data might have been helpful in part 5 especially due to the darkness when own speed was reduced to 20 knots i.e. when operators had more time to do more thorough examinations due to lower speed.

Relevant elements can be summarised as follows:

- The radar was not tested before it needed to be used
- Radar was only adjusted when needed
- High speed demands rapid decisions which sometimes exclude the possibility to utilize all the possible electronic anti collision aids
- Most decisions are made based on optical observations alone
- AIS targets are generally not activated and data are not read
- Trails are randomly used
- Automatic acquisition and “fusion of targets” are never used. These would probably not be suitable in inshore high speed navigation but have never been tested

- The two navigators often reached a state of high workload, sometimes caused by work carried out in other areas than navigation

4.2 Findings from simulator observations

4.2.1 Introduction

The purpose of the simulator tests was basically the same as for the live navigation: to observe the use of radar and AIS for anti-collision in an IBS environment, and to observe the ability to utilise the radar and AIS for detection and evaluation of targets, in other words, to take proper action. The observations supported the thesis objective 1 directly and objective 2 indirectly. As in the live observation the candidate did not know the purpose of the observation; they were supposed to navigate as normal.

The obvious advantage with the simulator is that it was possible to create many relevant potential collision situations to achieve a larger number of observations than in live navigation. All the teams were exposed to the same scenario which presented a possibility to make comparisons.

4.2.2 Scenario # 1: Inshore but open waters

Scenario #1 took place in a main shipping route north of Bergen with a lot of traffic including oil tankers entering to and from an oil refinery. The waters are quite open with a fairly low level of navigational difficulty which assured a main focus on the 3 targets T1, T2 and T3. These targets were all planned to be on collision course (see Figure 4-5).

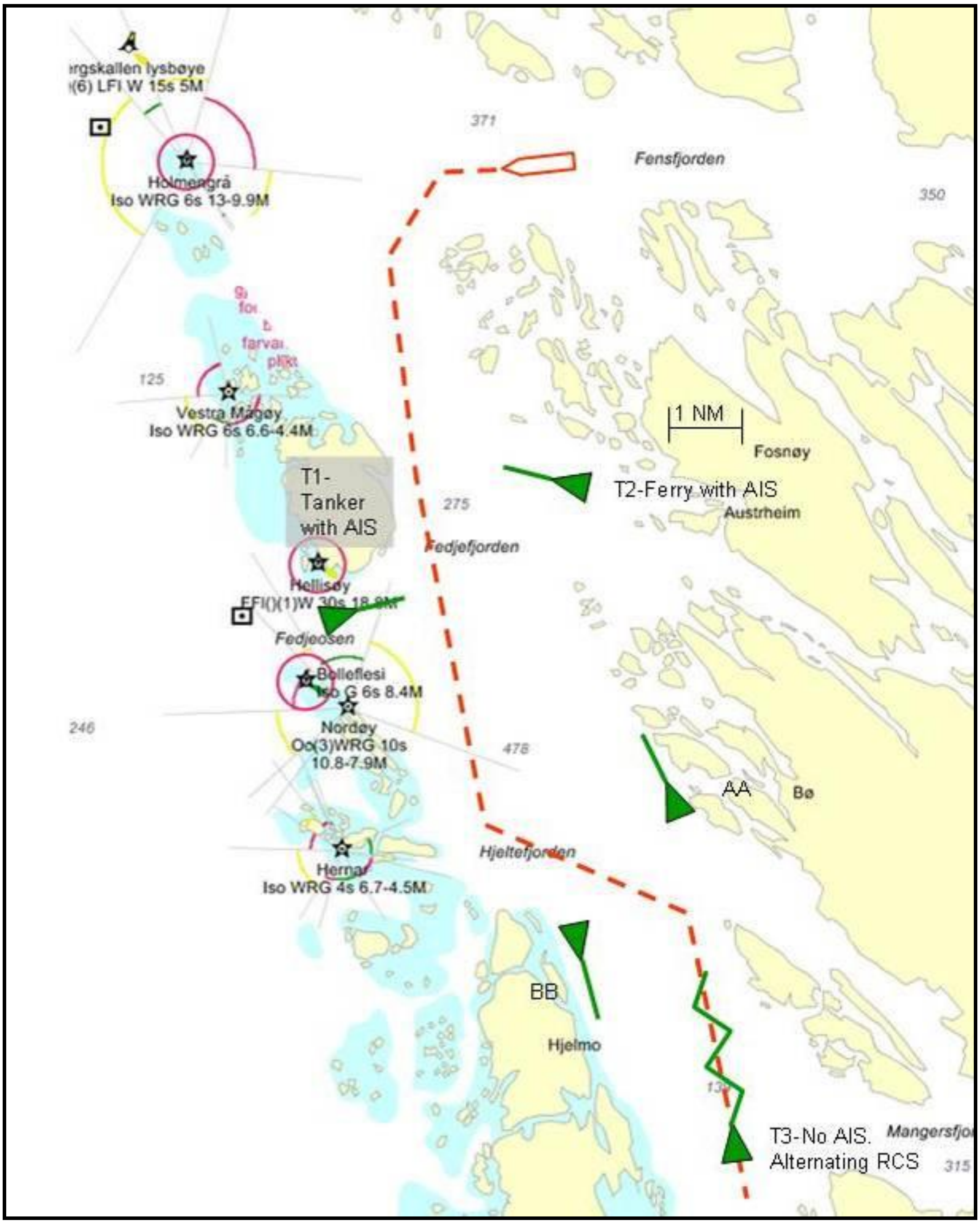

Figure 4-5: Overview of scenario # 1 setup in simulator

Target no.1 (T1) was a tanker with a fully functional AIS and had the right of way.

Target no.2 (T2) was a ferry with a fully functional AIS approached from port without the right of way.

Target no.3 (T3) was a smaller fast-ferry heading opposite courses. The echo was "coming and going," technically done by adjusting by the targets radar cross section (RCS) value. T3 had no AIS and the target was changing courses regularly.

Various other contacts (AA, BB, CC, and DD) all had fully functional AISs, but did not present any collision danger.

The weather was poor with darkness and heavy sea state of 2-3 metres. The visibility of ship navigational light was 2 nm.

Figure 4-6: Frigate simulator, scenario at night

4.2.3 Team 1, Scenario # 1.

The navigation team consisted of two fully trained and certified navigators together with one helmsman, one lookout and one assigned radar operator. This configuration of the navigational team is one or two persons more than usually would be used in this situation. Own ship was a Fridtjof Nansen Class frigate doing 22 knots.

The mode of navigation was "combined visual and radar." Throughout the test, the navigators focused on the ECDIS as their main source of information. The collision alarm initiated the interest for AIS target T1 and T2 that were discovered on the ECDIS. The target evaluation was done on the ECDIS but the information of the targets on AIS was never read. None of the AIS targets were activated by the operators and the radar was mainly used for PI to ensure safe positioning. Since the AIS data was not read, the navigators were not able to identify T1 and T2 until they were spotted visually. In spite of 5 persons in the navigation team, not all available information was explored to achieve a better SA. If the team had read the information, they would have known that it was a tanker that most likely would turn north towards the refinery after entering the fjord. After the tanker was spotted visually, all the decisions were made on the basis of optical bearings.

Figure 4-7: T1 Passing the bow of own ship

The solution to clear T1 (see Figure 4-7) was to turn starboard but only turn 5 degrees which was not enough to make a clear statement to T1 as demanded in COLREG. Rule 7 c describes how assumptions will not be made on the basis of scanty information. The navigators should be especially aware of the danger of making small course alterations when the target close (Cockcroft and Lameijer, 2011). In this case the decisions were made on scanty information even if more correct information could easily be obtained.

No one attempted to alter scale or optimise the picture on the radar. Relative vectors or EBL were not used, but the OBD was used to some extent.

T3 was discovered by the radar operator 15 minutes later, about 3 nm ahead and proved hard to track as planned. As for T1 and T2, the decisions to avoid T3 were made after visual observation even if this was a smaller ship and harder to see.

The team was not very much concerned with the contacts AA, BB, CC and DD, which did not as such contribute to any relevant findings.

4.2.4 Team 2, scenario # 1.

The navigation team consisted of two fully trained and certified navigators together with one helmsman, and one lookout. Own ship was a Fridtjof Nansen Class frigate doing 22 knots and the mode of navigation was "combined visual and radar."

T1 and T2 were discovered on AIS 4 minutes earlier than Team 1. The radar operator worked well to achieve an optimal radar picture but T2 was never tracked, never constituting a threat. Hence focus was on T1 which also was tracked on radar as soon as it was possible. T1 was also activated on AIS, but data was not read. Relative vectors were utilised, but the OOW decided to contact T1 by VHF to agree on the passing. The radar operator used the radar well and discovered T3 4 minutes after the echo was visible the first time on radar. AA and BB were also discovered on AIS but the data was not read as the contacts were assessed not to be a potential danger.

The settings for collision alarm were default, not known by the operators and never adjusted.

4.2.5 Team 3, scenario # 1.

The navigation team consisted of two fully trained and certified navigators operating the IBS on the Skjold class simulator (Appendix B). The initial speed was 42 knots and there was no attempt to optimise the radar picture or to adjust trails or alarm settings. Nevertheless, the picture was fairly good but the scale was not changed to look further ahead. The AIS symbol of T1 and T2 were discovered after 7 minutes at a range of 6-7 nm. 10 minutes later T3 was detected on radar at 6 nm. Because of the high speed, own ship passed in front of both T1 and T2 which never represented any danger. However, the main focus for the radar was safe positioning of own ship. Relative vectors were not used, but optical including OBD were used to detect relative motion of the targets. AA and BB were both detected by AIS but never considered by the team.

4.2.6 Team 4, scenario # 1.

Team 4 consisted of a navigation team of two fully educated navigators from the final year of the Royal Norwegian Naval Academy. They had only live experience from the Naval Academy training vessels, *the Kvarven* and *Nordnes* (Appendix B). They had, however, not yet commenced the training on board an operational naval ship.

They used a generic corvette model of 50m length. Speed was 22 knots.

T1 and T2 were discovered by AIS and T1 was tracked by radar as soon as target became visible on the radar (see Figure 4-8).

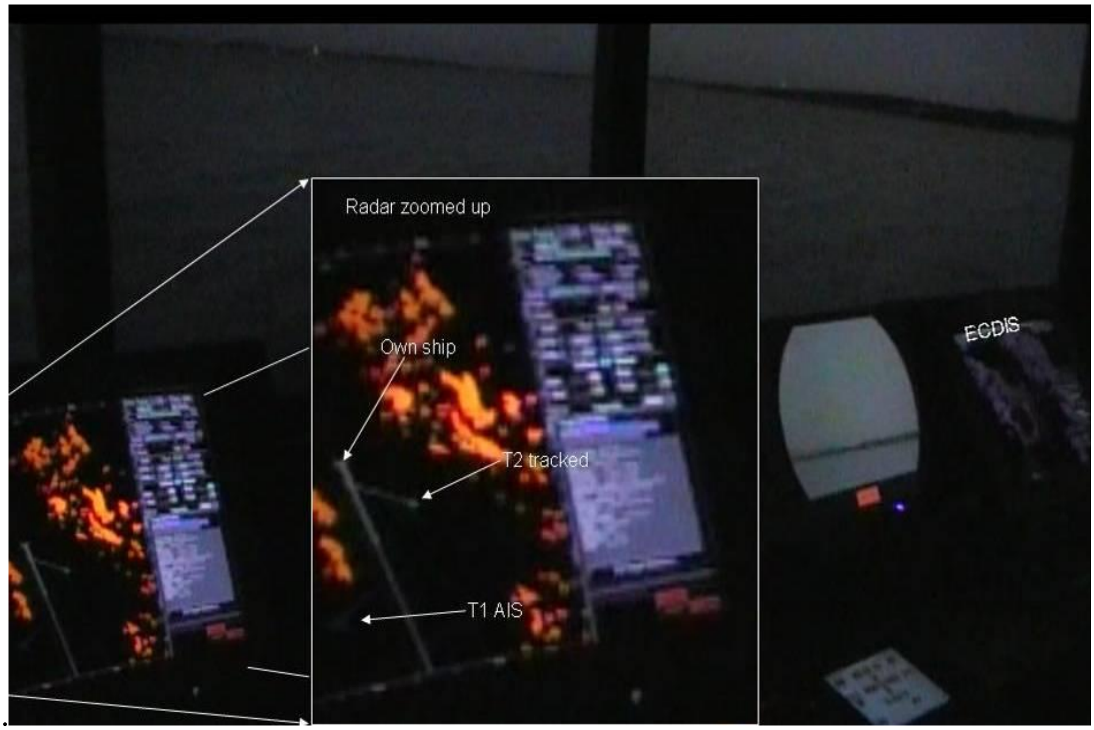

Figure 4-8: Section of the bridge showing T1 and T2 on the radar.

The radar operator adjusted the radar picture but did not access the alarm settings. T1 and T2 were discovered by AIS, and as soon as they became visible, they were tracked and relative vectors were utilised. Trails were on.

The radar was mainly used for positioning, but was also used to search for contacts and evaluate the collision risk. There was much focus on how to handle T1 and T2. T2 was avoided by turning starboard and after looking into the data of the AIS, they called T1 to agree on passing each other.

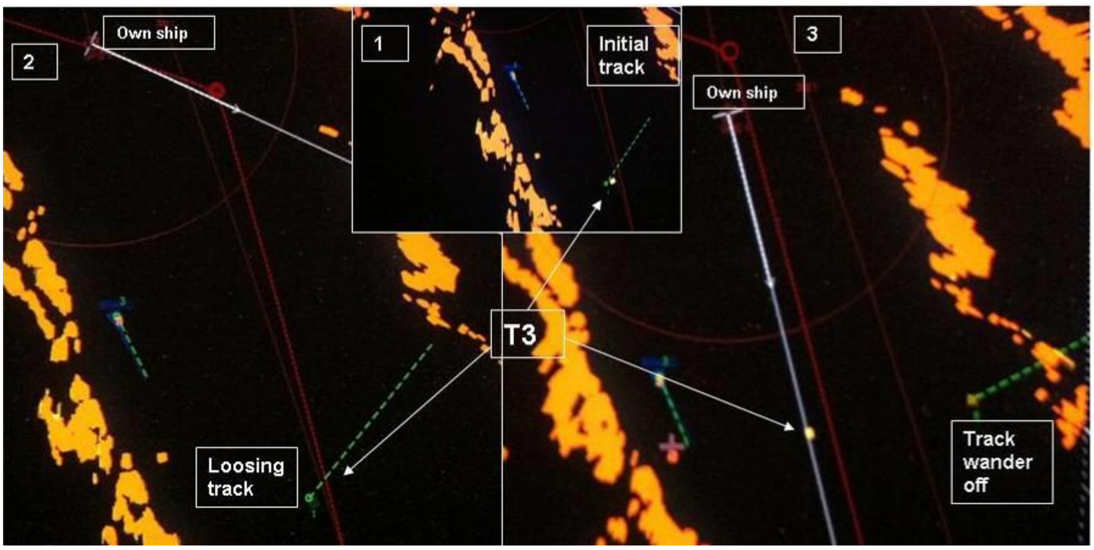

Figure 4-9: 3 sequences of the radar showing T3 proving hard to track.

Along with the other teams, team 4 found it problematic to track T3 due to the planned alteration of radar cross section, RCS (simulating a small target in rough sea). In addition, T3 did not have AIS, they lost track several times and T3 wandered off (see Figure 4-9, part 3). This caused a lot of attention which stressed the navigation team. It made them alter course several times and abandon their initial route. However, they worked hard to keep SA and mainly after assessment by visual observations, they managed to achieve a safe passage of the contact.

4.2.7 Summary scenario # 1.

- No teams performed the initial control and adjustment of the radar
- Collision alarm and AIS on radar and ECDIS made the teams aware of the contacts
- There was no deliberate attempt to adjust alarm settings and only one team considered used trails
- Except for team 4, there was no attempt to use relative vectors or electronic bearing lines (EBL)
- Radar was mainly utilized for positioning and the main control method was PI
- All teams focused on visual observations and some used the OBD
- No targets were manually activated, they were only activated via collision alarm
- Teams with long experience used electronic aid less than teams with shorter experience.

4.2.8 Scenario # 2: Narrow waters, many contacts with and without AIS.

The simulated scenario took place in a familiar main traffic route outside the naval base. The weather was typical autumn with rain and 1 metre wave height. The visibility was only 2-400m and it was dark.

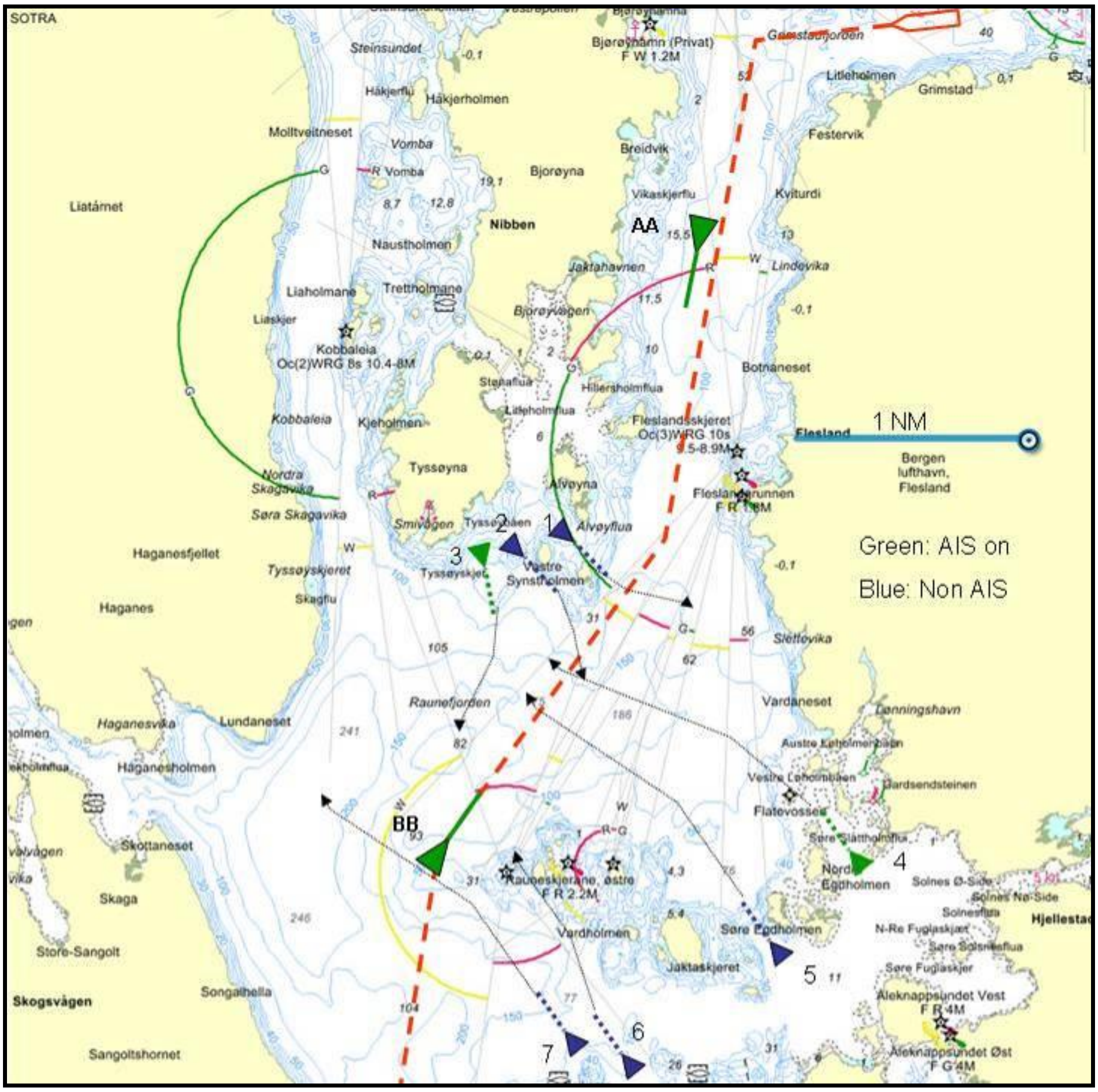

Figure 4-10: Overview of the initial setting of scenario # 2

As illustrated in Figure 4-10, the main focus of this trial was the 7 small (40-50 feet cabin cruiser type) boats. All the contacts were moving from an area with small islands where they were hard to separate from the islands and rocks on the radar. Two were equipped with AIS, but five were not. All would be on collision course sooner or later.

Two other AIS vessels, AA and BB were transiting in the main fairway with AIS, easy to spot, without being any major threat.

In addition to the observation elements in scenario # 1, scenario # 2 also investigated if the navigators were able to spot moving targets between the small islands and rocks and if they were "blinded" by the fact that there were several AIS contacts in the same area (all expected to have AIS). For this reason the scenario included more contacts than there would normally be in this area.

4.2.9 Team 3, scenario # 2

Navigation team 3 consisted of two fully trained and certified navigators operating the IBS on the Skjold class simulator. The initial speed was 42 knots but they soon reduced speed based on poor visibility, traffic and contacts ahead, but before any of the non-AIS contacts were detected.

AA and BB were both detected early on AIS and tracked later. At the start of the scenario, the overtaking of AA took all focus for some minutes, giving little time to search for other contacts. Simultaneously a lot of attention was given to positioning of the ship which led to a degree of overload.
Contact no 1 came as a surprise and were only avoided by turning port and making a full stop. Contact nr 3 (see Figure 4-10) was tracked and was AIS equipped, taking most of the focus as it was on collision course and hard to track. At this time, none of the other contacts were detected, and although the team worked to adjust the picture, they never turned on trail which could have made it easier for the detection of the non-AIS targets. Also, the team never had time or found it relevant to read any of the AIS data. Several of the contacts without AIS were not detected (see Figure 4-11)

Even if the visibility was very limited, the team partly based their decisions on visual observations of targets in order to decide on manoeuvres to avoid collision. The scenario was challenging and it put the team close to a state of overload that forced them to reduce speed of advance to be able to achieve safe navigation.

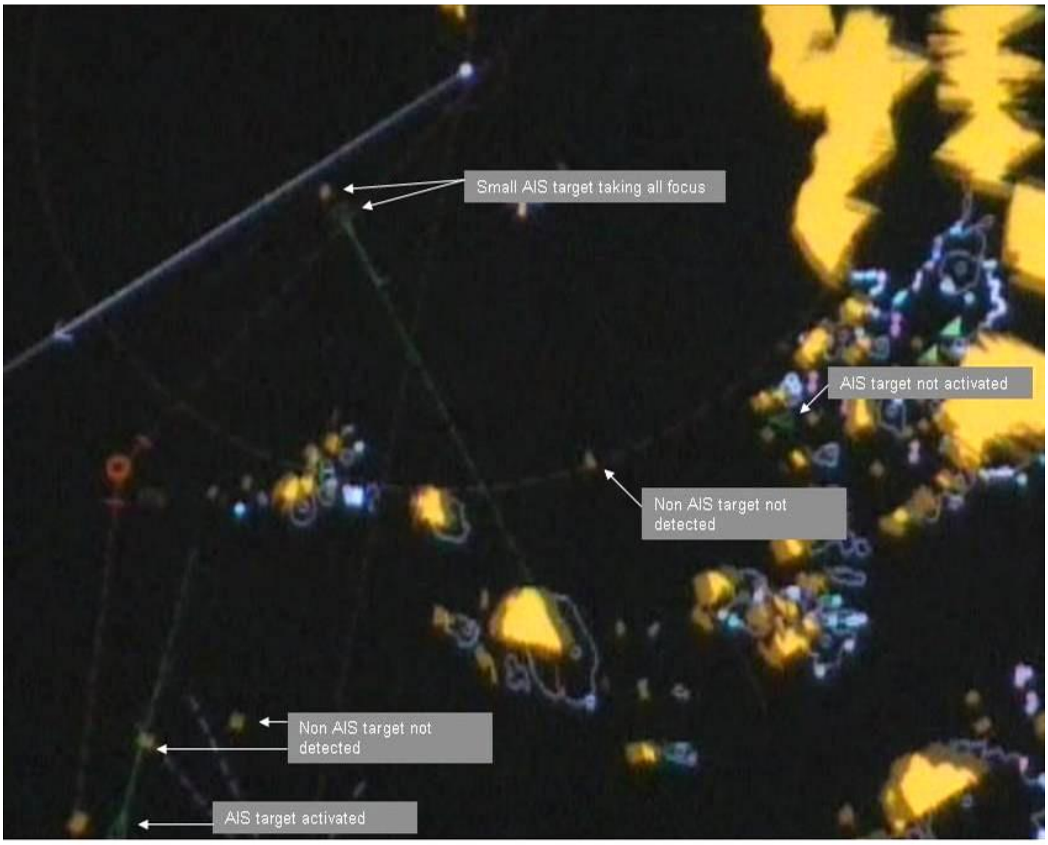

Figure 4-11: Radar picture from team 3 showing different targets and their status

4.2.10 Team 4, scenario # 2

Team 4 consisted of two fully educated navigators from the final year of the Naval Academy (see paragraph 4.2.6). The same corvette model as in scenario #1 was used, but the initial speed was reduced due to the environmental conditions.

Team 4 discovered AA and BB early on AIS. The overtaking of AA was done with distinct course change as demanded by the COLREG. They managed to follow the planned route without too much diversion but by changing the speed instead. (see Figure 4-12)

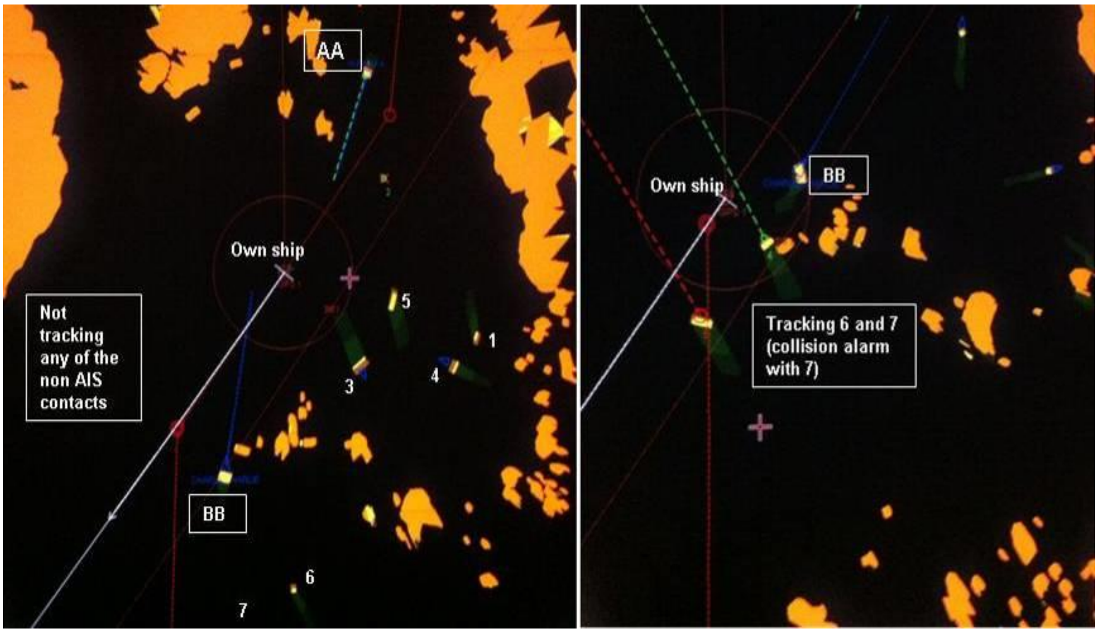

Figure 4-12: Radar picture from team 4 showing contacts with and without AIS

Positioning and decision making related to AIS contacts that resulted in a late discovery of the non-AIS track had main focus, but nearly all were detected as they had turned on trails. The team also tracked AIS contacts but never gave priority to reading data. Relative vectors were used but not EBL and OBD.

4.2.11 Summary of scenario # 2.

Many of the same findings as in scenario #1 were experienced. Again team 4 was the only group using trails, working to improve the radar picture. This scenario had worse optical conditions than in scenario # 1, but the navigators would still to a large extent prioritise information obtained by optical means as basis for their decisions.

Taking into consideration that the scenario introduced a somewhat unrealistic amount of contacts, it showed that contacts without AIS are more difficult to discover in areas with many contacts in a littoral area with several other land echoes. In this scenario VHF communication would perhaps be an appropriate measure of informing the ships AA and BB, and to warn off several smaller contacts, but the VHF was never used.

4.3 Description and questionnaire analysis

4.3.1 Introduction

The purpose of the questionnaire was to do research on navigators' knowledge on anti collision aids. To ensure similar conditions and comparable answers, the questions and answers were presented and noted by the author of this paper. All 19 navigators were interviewed during two days.

17 officers served on operational ships while 2 were last year students from the Naval Academy. The average experience as navigators was 2,5 years (2, 8 years not including the students). 15 officers were serving on the Skjold class coastal corvettes (FPBs), and 4 were serving on the frigate, Fridtjof Nansen class (FF). 10 had already passed training for independent officer of the watch (OOW), while 9 were on different levels in their training to become an OOW.

The first question was designed to look into how the candidates would prioritise the sensors. The 19 next questions were divided in two levels of difficulty. First level was user related and the next was designed to examine a deeper understanding of the system.

4.3.2 Prioritising of sensors

The first question described a realistic scenario, transiting in daylight and in the dark, inshore in the main traffic routes of the Norwegian littoral area (Appendix C), where different sensors failed, but only one at the time. The officer was to decide if the failure of one sensor was critical (have to stop), partly critical (continue but delayed) or not critical (no implications) to achieve the mission. The most valuable part for this thesis was the evaluation of radar, AIS, ECDIS and log, but it was necessary to include all the sensors to cover the main focus and to be able to compare the answers. However, in one way or another all the sensors might be relevant directly or indirectly as aids in anti-collision.

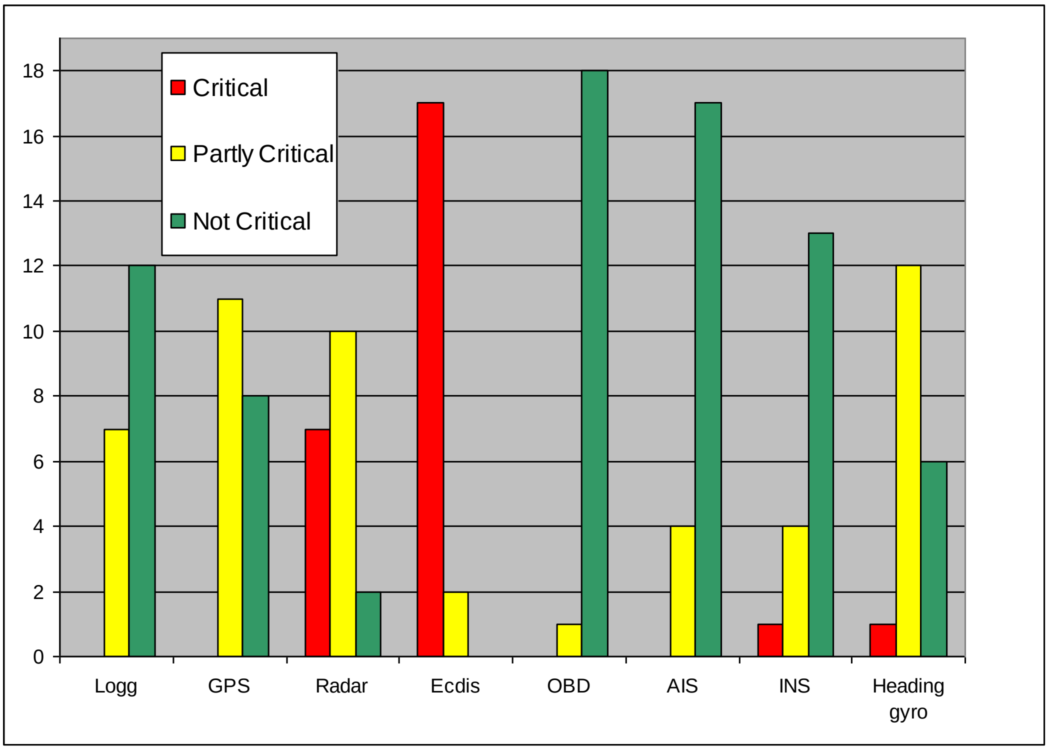

Diagram 4-1: Evaluating the importance of sensors after failure

Diagram 4-1 presents the results of how the navigators prioritised each sensor under the circumstance that one would fail but all the others continued to work. The answers show how each officer would value each sensor in the given scenario. 17 of 19 officers stated that the ship would have to stop without ECDIS and no other map would be available; a sensible and logic answer that was not hard to predict. The other sensors that were relatively easy to decide upon for the candidates were the OBD, INS and log; the majority agreed that the failure in these sensors would not affect the mission. Most of the candidates expressed that they would very well manage without AIS and log, yet doubt existed whether the log was important or not. Settling on radar or GPS proved most difficult, and it was interesting to notice that more than 50% decided that they would achieve the mission but with delay even if the radar failed. On the other hand, no one valued GPS to be critical.

4.3.3 Discussion first question

Analysing the response to the ECDIS failure question alone is not enough to make a significant trend, but viewing ECDIS, radar and GPS together, there is an indication that although radar and GPS are important, they are not critical. This finding coincides with the findings of O.S. Hareide's MSc (2013) which describes how navy navigators are trained to navigate without trusting the GPS. It looks as if the ECDIS may present the navigators with all they can handle, thus automatically turning into the primary aid in the IBS. This thesis (ibid.) describes that civilian navigators are much more dependant on GPS than their military counterparts. These findings confirm the fact that to navigate a warship the navigators are being taught not to depend 100% on GPS, and are thus regularly trained to navigate without GPS and AIS input. However, the given scenario was a transit in peacetime, in the dark, and it was important to arrive safely i.e. the only explanation why the majority would manage without radar would be the trust in the ECDIS and the ability to evaluate the used sensors accuracy underway by other means than radar.

The insecurity in the answers concerning log, INS and heading gyro could partly be a result of shallow knowledge of the complex integration of the sensors which coincides with the experience expressed by NNC (NNC, 2009) which mentions the complexity in the new IBS.

4.3.4 Analysis of knowledge within radar and AIS

The questions were aimed at measuring the level of understanding within an area that is relevant for optimal use of both radar and AIS in anti collision. The detailed score in each question and each candidate are listed in Appendix D. Questions 1 to 12 represent subjects often addressed by the navigators during their normal work day. They are more likely to have knowledge of these than the last section of questions. Questions 13-19, on the other hand, are further remote from daily operations, but are still relevant for optimal utilisation of the navigational aids.

As expected, the scores were higher in the first part shown in Diagram 4-2.

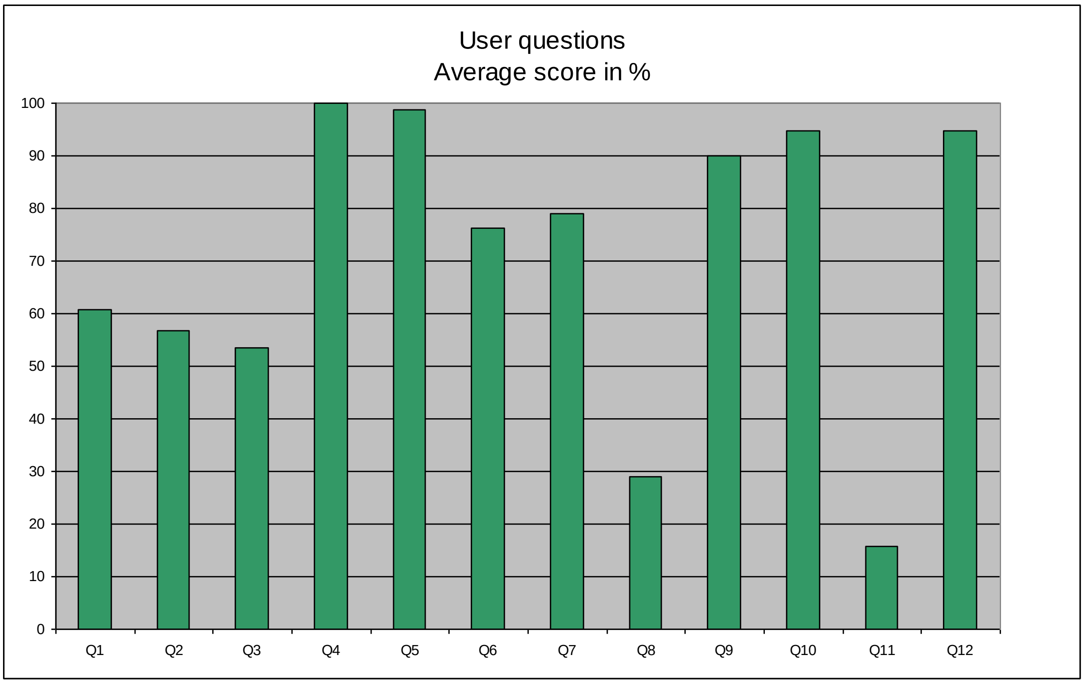

Diagram 4-2: Level 1. User related questions

The overall average score on Q1-12 was 71%, an acceptable total level. However, based on these questions level of difficulty, the scores on some of the questions could be regarded as too low for navigators at this career level.

Question 1 (Q1) asks about the mode NUP/FT, which is the most frequently used radar mode. Very few had complete knowledge of how it worked, indicated by an average score of 61%, yet most had a score around 50%.

The basic knowledge to support the decision to choose 9 or 3 GHz radar is generally too low with only 53% score (Q3). However, the Skjold class has only the 9 GHz radar for navigation, not giving the navigators a chance to practise the use of two different navigation radars.

Q4 addresses adjustments of the radar to optimize the radar picture. These adjustments are executed regularly, which is probably the reason for the high score. However, Q16 (Diagram 4-3) which is a more complicated question within the same area, shows that there is lack of technical understanding.

Q6 is simply asking about the criteria for collision alarm which is very vital in anti collision and experienced on a daily basis. The average score is good (76%) but too few knew that the target had to violate the TCPA as well as the CPA.

Fusion of targets (Q8) has not been explored or used by any of the navigators and thus achieves a score as low as 29%. Q11 also stands out in a negative way with a mere 16% score. Only 3 persons knew that the name of the ship is transmitted every 6 minutes in the AIS system. This result is surprising as everyone stated that they had seen many times that the name appeared after a while. Some expressed that they had never thought about it, and some believed that it had to do with the target range. Again the data shows that there are basic gaps in knowledge and perhaps more worrying, no urge to find out "why." Ultimately, the wrong answers might be transferred from the experienced to the young officers. Nevertheless, the results of the rest of the questions were quite satisfactory, perhaps better than what could be expected.

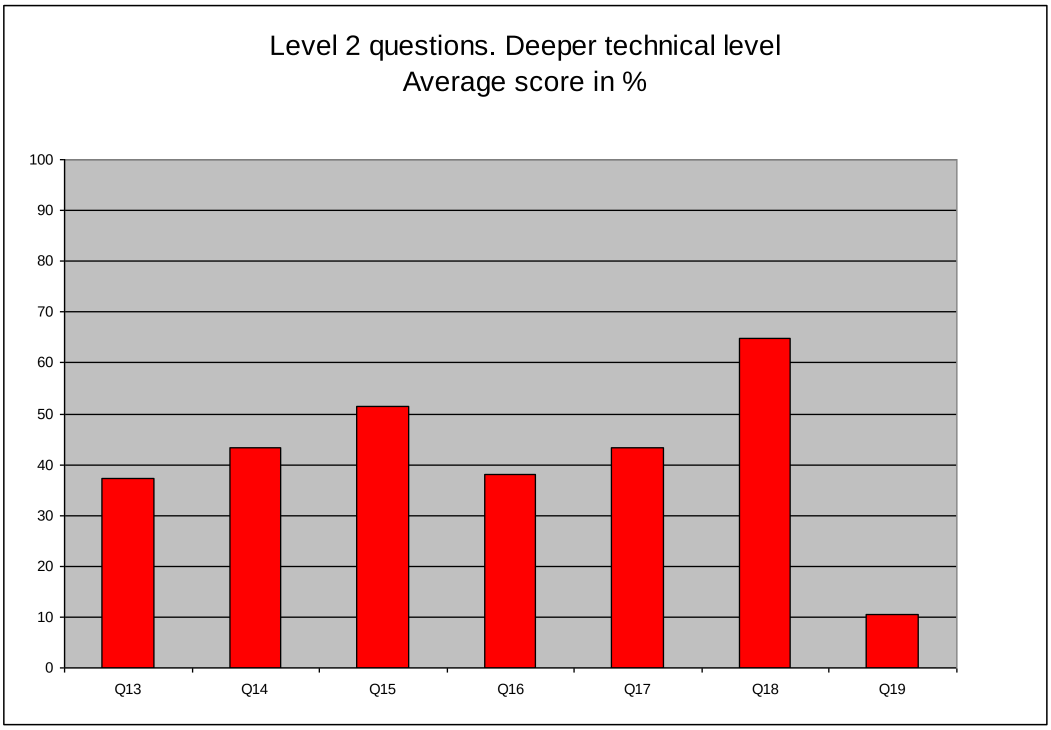

Diagram 4-3: Level 2. Deeper, technical level questions

The more technical level questions returned a score of a total average of 41% with the lowest 10% and the highest 65% (see Diagram 4-3). Q19 has the lowest score which may be explained because it does not very often happen that the ship name is jumping from one target to another in spite of the fact that there has been a problem when larger naval ships give the same MMSI nr to the mother ship and their rigid-hull inflatable boat (RHIB).

For 6 out of 7 questions the overall scores were more uniform than the "user level" questions. In addition, the navigators knew almost the same part of the answer which indicates that this technical level is mainly forgotten after the officers start their operational duty. When the answer was explained, most of navigators responded that they had not thought about this since school. However, in most cases, it should be possible to operate the AIS and radar on a daily basis without having a deep understanding, and perhaps it is too much to demand that every navigator should be at this level. On the other hand, it might be compulsory that the knowledge is present and available on each ship, e.g. one dedicated expert on each ship. Nevertheless, there is no doubt that the navigators would benefit from understanding the systems better.

Naval ships have used AIS for several years and all navigators have the mandatory AIS course, having experienced it at a practical level. AIS is a recent technology compared to the radar but most of the navigators involved in this thesis have experienced AIS and radar from the start of their careers. Q14 addressed the strengths and weaknesses of the AIS and the radar, but none of the candidates had ever considered comparing the two systems in this respect and thus delivering a low score.

Automatic acquisition was addressed in Q15 and the response was much the same; "we never use it, so I don't know." The question gives away some of the answer, but no one knew that it also inflicted AIS. Question 7 (Diagram 4-2) also asked about automatic acquisition at easier levels, returning nearly 80% which indicates that the easier bits were known but the more technical understanding was only mastered at a superficial level.

4.3.5 Questionnaire summary

It is reassuring to learn that the navigators are trained to continue navigating even if sensors like GPS would fail (Hareide, 2013). Nevertheless, there seems to be a great dependency on the ECDIS and perhaps a slightly less reliance on radar. Considering the fact that there might be situations where the use of radar on military ships must be kept to a minimum, this is in accordance with navy policy. Still, this should not be a reason for not having able knowledge of all the sensors available, including the radar.

It is reasonable to assert that there is a great deal of radar and AIS knowledge within anti-collision area of interests. However, it seems like there exist significant gaps in the navigators' knowledge both on the "user level" and the advanced technical level.

The navigators complain about too complex systems and too much to learn in a short time. This finding is also underlined by the Navy Navigation centre in their presentation and paper, discussing complex systems and knowledge gap (NNC, 2009). The navigators participating in this research all showed an extraordinary dedication and interest, being very keen to understand the questions being raised. However, several officers expressed that there is not enough time to maintain and increase knowledge on a daily basis.

The officers are from the beginning trained to navigate even if systems fail and they therefore, especially in the start, focus on visual and manual modes. The answers indicate that experienced operators are likely to have more confidence in radar, giving the radar higher priority and value in the IBS.

Concerning the automatic functions such as e.g. “fusion of targets” and “automatic acquisition,” there is a correlation between the knowledge and user frequency. It also seems like the navigators often knew “half” of the answers and when confronted with this, they did not feel comfortable about it. They mainly explained this as a result of shortage of time and that nobody asked them to produce a profound insight into these topics.

All the navigators had completed the formal education at the highest level (STCW 95) at the Naval Academy, conducting or completing a training program at the operational units. It is of course never possible that every curricular item will be remembered, but this thesis suggests that most of the advanced technical understanding is hard to maintain during operational duty. Nevertheless, it also showed that good knowledge was present within several important user level domains.

5 Conclusion and recommendations

Due to the long and challenging coastline of Norway, navigation skills have proved to be a crucial factor for the Norwegian navy. Based on long traditions, all naval units spend much time and effort to navigate faster, safer and tactically better. For decades radar has been the most important electronic tool to ensure navigation at an acceptable risk level.

After the introduction of computer based, paperless bridge systems, a new level of benefits and challenges was introduced. It was now possible to give the navigators a new set of tools, and it was technologically possible to do things faster and with a higher level of automation and precision. When the first electronic charts were introduced on board the operational ships, not much training was assessed to be necessary. However, after some years of experience, the NNC found that the transition had not been as expected (NNC, 2009). With the new system followed a demand for more education and training. Other factors experienced were the complexity of the IBS, the possible information overload and user “unfriendliness.” The accident statistics underlined the new challenges; the number of collisions was reduced until 2007, but then started to increase again (NMD, 2010). In 2000 there were only 4 more collisions than in 2010 (Figure 2-5). For comparison, the numbers of groundings decreased in the period 2000 to 2004, but from then on showed a significant increase until it stabilised in 2007.

The COLREG came into force in 1977, serving as a good platform to avoid collision. In their book, however, Cockcroft and Lameijer describe the necessity for a clear understanding (2011) . AIS is not described in the COLREG but is clearly an aid and must therefore be interpreted as being included in the wording “by all available means” in rule 5 (Norris, 2008, Patraiko, 2013).

As Dr. Norris (2008) points out, the radar has been developed over 60 years and has for decades been the single most important anti collision electronic tool. The introduction of IBS and especially the introduction of ECDIS have been described as a revolution, having forced the shipping industry to rethink how education, training and safe navigation are done. The RNoN experienced this as well, and in 2013 the NNC issued the military publication *SNP 500* containing recommendations and regulation to achieve safe and effective navigation (NNC, 2012). An important anti-collision tool is the AIS that to some extent presents the navigator with an alternative to the radar, but with a total different technology. The digital communication between ships makes it possible to exchange much needed information that was hard to get hold of earlier. Nevertheless, only a small part of the information is relevant in an anti-collision perspective. The radar being an old invention does not mean that it is outdated. On the contrary, the radar has been constantly developing into new types with new technology to perform better in general and especially under difficult conditions. However, with the introduction of computer technology, the radar has given the navigators more possibilities then ever before. There are more automatic functions like automatic acquisition and definitions of acquisition area. The menu system on a modern radar looks like a PC with complex menu systems that is not always fully understood by all the users.

From the literature review there was an apparent trend that insufficient utilisation of radar, AIS, and the lack or incorrect use of look-out were important factors in many accidents. The research of collision reports from Norway (NMD, 2010), UK (MAIB, 2004) and Australia (MCA, 2007) have revealed that there is still a challenge regarding the utilisation of electronic radar and AIS to avoid collision. The “Bridge watch keeping safety study” from MAIB concluded that 73% had improper or poor use of radar. These findings are from 2004 but are unfortunately verified from time to time, e.g. the collision between *Far Swan* and the barge *Miclyn 131* in 2010 stated badly tuned radar, inappropriately set up AIS and bad look-out as some important factors contributing to the collision. Several reports also mentioned in detail the lack of understanding of the technology and the failure of using simple aids as trails, relative bearings, optical bearing, EBL and similar.

If the modern IBS might place the navigators in an overload situation, it could be seen to actually counter effect the creation of better situation awareness, in worse case making better decisions difficult.

All the ships in the RNoN are being equipped with IBSs, complying to as many as possible of IMO’s performance standards, as recommended in the current radar performance standard (IMO, 2004).

With the technical development, and the transition to modern IBS in mind, this thesis aimed to look at how the RNoN has performed after the transition to IBS. The objectives of the thesis were to:

1. *Identify and examine* the use of AIS and radar in anti-collision by live observations and simulated tests
2. *Explore* the knowledge of radar and AIS use relevant for anti-collision
3. *Formulate* recommendations on the education and training within radar and AIS

To support these three objectives, the fieldwork consists of three parts: live observations, observations in the simulator and interviews.

The live sailing was 600nm transit inshore Norway coastline both in light and dark conditions and at varying weather conditions on board a Skjold class FPB. In the simulator two different areas and scenarios were designed to achieve as many relevant actions as possible. Within the limitations of the questions, the questionnaire measured the knowledge of the operators regarding the understanding and use of radar and AIS on two levels of technical difficulty.

The findings in this thesis have definitely showed that the challenges are also relevant for the naval navigators observed during the field tests.

During the trials there were never fewer than two qualified navigators executing the navigation, and several times the teams were complemented with helmsman, look-out, or extra operators. In spite of this, there were several occasions where the teams did not have time to operate and utilise all available anti-collision aids. The reasons for this are most likely down to several different factors which lead back to the objectives of this thesis. The RNoN navigators have a comprehensive and structured education and training which probably are more comprehensive than civilian navigators. Nevertheless, the findings indicate that the operators might not fully utilise the radar and AIS the way it was intended. Conversely, they also showed that they are able to handle advanced, potential collision situations by making highly qualified decisions in high speed and in challenging environments. Another clear trend is that all navigators had been trained very well to use visual observations by evaluating situations looking out the window or using the OBD (Figure 2-1), common on all naval ships. In fact, visual observations were always a vital factor when the OOW made anti-collision decisions even if other useful information was available. On the other hand, the electronic aids, activating the AIS target, tracking targets, choosing trails, using relative vectors, or EBL were rarely investigated before decisions were made.

The MAIB reports (2004) mention the lack of look-outs in several incidents. During the observations a look-out was always in place and well trained in accordance with STCW 95. Only on the Skjold class the look-out function was carried out by one of the two navigators when the situation allowed it. Under certain circumstances listed in the STCW 95 regulation II/1 section 4, this can be justified (IMO, 1978). The look-out duty is divided by the two navigators and normally works well. However, the extra task adds an extra duty to the team, and in times of high workload it may lead to reduction in the quality of the look-out duty.

Except from automatic radar tuning that was always activated (default) and the occasional use of automatic clutter control, no “automatic” functions like the “automatic acquisition”, or the “fusion of targets” were deliberately activated. AIS targets were seldom activated and except when finding the name of the ship, the data from these contacts were not often read. The AIS tracks were automatically activated when the criteria for the collision alarm were met. Unfortunately, no one ever adjusted these criteria and the knowledge in this subject proved to be average which could be expected when nearly never operated.

The findings during live navigation support the analysis of the first question where ECDIS tended to have higher priority than the radar. Due to the integration of AIS with the radar, ECDIS was the primary source of information. In periods with restricted visibility due to rain and/or darkness the radar received more attention, but the ECDIS was still the main source of information in the IBS. Operating the ECDIS was often prioritised over the radar. Hence the operators used a relatively small amount of time to make sure that the radar was optimised for the fast changing situations.

When rapidly assessing whether a contact is on collision course, an easy technique is to observe the change in relative bearing of a contact. There were both optical and electronic tools available, but in some cases the navigators made measurements based on just looking at the contact which works well if there is a high rate of change in the contact bearing. However, this method was also used when the rate was only slowly altered. In some cases in the simulator, the OBD was used. The electronic radar aid, “relative vectors” was seldom utilised.

Echo trails can make it easier to distinguish the targets from small islands and “aids to navigations” (ATON), but few used it deliberately to increase the SA. The importance of this relatively simple tool is described in the collision between MV *Spring Bok* and

MV *Gas Arctic* where “relative vectors” were an important factor contributing to the accident (MAIB, 2012).

In addition to the question of how navigators prioritised the different navigational sensors, the other questions were divided in a technical part focusing on system knowledge and a more user related part. The overall findings from the questionnaire were that the knowledge in user related questions was considerably better than the more technical ones. The operators had no knowledge of the functions that they never used during the live sailing and simulator tests. However, there was some good knowledge in the user related questions but also some inadequate, e.g. very few had a complete knowledge of how their most used radar mode worked. Still, the knowledge in how to optimise the radar picture was good. Nevertheless, when they were asked to explain rain and sea clutter technically, they had not thought about this since school.

These findings may indicate that there is not much time or initiative to research and find out how the IBS works on a daily basis. There was definitely no lack of interest when the subjects were raised and most of the candidates expressed a curiosity and willingness to learn more during the interviews.

It is a fact that the modern naval ship is more technologically advanced than ever before, and it is a question whether the operators are given enough time and effort to learn and understand the system at a level that would make them utilise all anti-collisions aids to a satisfying degree. This thesis coincides with the article by the director of MNA who claims that modern navigation needs much more training than what the certificate calls for (Teisrud, 2007). However, the thesis shows that in order to master the new systems, dedication, and constant willingness to learn about the new topics, as well as relentless testing, experiencing the unknown are required.

The extensive use of visual evaluation is good practise, proving that the navigators have not been deluded to rely only on what is presented on the screens. Nevertheless, it seems as the operators use the same methods on every occasion, not utilising and exploring other combinations of aids included in the IBS.

5.1 Synopsis of objectives

Within the limitations of the thesis, the first objective has been complied with to a satisfactory level.

- Both radar and AIS are being used as an anti-collision aid, but not all the electronic features are fully understood and used the way they are intended
- The navigators are being taught from the beginning of their training that the truth is found by looking out the window. Generally, this is a very sound attitude, but the ideal procedure would be to combine all the different aids, including visual, to achieve a better SA
- Most of the operators use the same method in every situation. Not one team utilised all the different features during the tests, e.g. relative vectors, EBL, OBD etc.
- The complexity of the radar and AIS in the IBS is in some scenarios too much to handle for the navigators who instead simplify and reduce the inputs leading up to a decision

The second object was to investigate the knowledge of the navigators. The thesis has provided an adequate overview of the level of knowledge.

- The level of understanding in the user level questions was in general good with the exception of a few questions
- The more technical part was not that familiar, indicating that the level of system understanding could be limited in some areas
- The operators were capable of using the system on a daily basis, but limited knowledge in some areas might hamper a maximum exploitation of the IBS
- Very few, perhaps none, of the candidates involved in this thesis had a near complete overview and understanding of the aids in anti collisions

The last objective aimed to formulate recommendations for the education.

- It is reassuring that the theoretical education at the RNoNA is in accordance with STCW 95, qualifying the students to the highest certificate level. However, the thesis demonstrates that there is a need for familiarisation and training when on operational duty (on the job training). The thesis discloses that not all aids are fully understood, possibly leading to less situation awareness.
  The operational units are recommended to arrange for a system that maintains and increases the level of knowledge within this area
- The systems are very complex and for an officer, there is a lot to learn. This implies that there has to be ample time and resources to carry out the necessary training for new officers, but also for the re-training of officers already being qualified as OOW.
- It is recommended that an OOW ought to possess higher proficiency within the technical system level before they are qualified as OOWs.
- The navigators should not be satisfied with utilising only one or two aids in anti-collision. A change of routine that would state that all aids should be tested at least once during a watch, would perhaps have the wanted effect.
- The final recommendation of future work is to research what level of knowledge and training will be sufficient for the different roles on board the different naval units.

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7 Appendices

Appendix A: Rules 5, 7 and 19 from the International Regulations for Preventing Collisions at Sea

Rule 5

Look-out

Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.

Rule 7

Risk of collision

(a) Every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists. If there is any doubt such risk shall be deemed to exist.

(b) Proper use shall be made of radar equipment if fitted and operational, including long-range scanning to obtain early warning of risk of collision and radar plotting or equivalent systematic observation of detected objects.

(c) Assumptions shall not be made on the basis of scanty information, especially scanty radar information.

(d) In determining if risk of collision exists the following considerations shall be among those taken into account:

(i) such risk shall be deemed to exist if the compass bearing of an approaching vessel does not appreciably change;

(ii) such risk may sometimes exist even when an appreciable bearing change is evident, particularly when approaching a very large vessel or a tow or when approaching a vessel at close range.

Rule 19

Conduct of vessels in restricted visibility

(a) This Rule applies to vessels not in sight of one another when navigating in or near an area of restricted visibility.

(b) Every vessel shall proceed at a safe speed adapted to the prevailing circumstances and conditions of restricted visibility. A power-driven vessel shall have her engines ready for immediate manoeuvre.

(c) Every vessel shall have due regard to the prevailing circumstances and conditions of restricted visibility when complying with the Rules of Section I of this Part.

(d) A vessel which detects by radar alone the presence of another vessel shall determine if a close quarter's situation is developing and/or risk of collision exists. If so, she shall take avoiding action in ample time, provided that when such action consists of an alteration of course, so far as possible the following shall be avoided:

> (i) an alteration of course to port for a vessel forward of the beam, other than for a vessel being overtaken;
>
> (ii) an alteration of course towards a vessel abeam or abaft the beam.

(e) Except where it has been determined that a risk of collision does not exist, every vessel which hears apparently forward of her beam the fog signal of another vessel, or which cannot avoid a close-quarters situation with another vessel forward of her beam, shall reduce her speed to the minimum at which she can be kept on her course. She shall if necessary take all her way off and in any event navigate with extreme caution until danger of collision is over.

Appendix B: Live training vessels and simulator

Figure 7-1: Live navigation training vessels at the Naval Academy (courtesy NNC)

Figure 7-2: Generic simulators (courtesy NNC)

Figure 7-3: Type specific 1:1 simulator for Skjold Class (courtesy NNC)

Appendix C: Questionnaire

Type of vessel (circle): Frigate, FPB, Mine, Others:

Years as navigator: .... Duty officer: yes no.

File No. Sony: .... Mark= 0-100%

nr	Question **RADAR/AIS CAT 1, User level**	*"Model answers"*	Answer	%
0	You are in transit from Bergen - Florø. It is reported good visibility all the way, but it's dark 20 nm prior to arrival. Prioritise the importance of the following aids to navigation on this trip, i.e. how it would affect the navigation if one aid is not working anymore. 3 possible answers: Not Critical, NC (will be safe with no delay), Partly critical, PC (will arrive safe but with delay). Critical, C (must stop and moor as soon as possible). Log, GPS, Radar, ECDIS, , AIS, INS, Heading Gyro	*Log: NC (Not critical)* *GPS: NC* *Radar: C (Critical)* *ECDIS: C* *Optical bearing device, OBD: NC* *AIS: NC –PC (partly critical)* *INS: NC* *Heading Gyro PC*	See appendix D.	See appendix D
1	Explain the mode NUP / FT ?	1. Land is moving. 2. Is confined to a square on the screen. 3. North up 4. Own pos fixed 5. True vector and trails. 6. A mix of true and relative mode 7. Radar is not adding trails on echoes that have opposite course and speed as own ship		
2	Pros and cons of mode NUP / FT?	1. Depending on good input log and gyro. 2. Easier to distinguish vessels from other echoes. 3. No need to reset own pos		

nr	Question **RADAR/AIS CAT 1, User level**	*"Model answers"*	Answer	%
3	How is 9 Ghz radar distinguished from 3 Ghz?	1. Shorter wavelength and better resolution 2. SART and Racon 3. Smaller antenna 4. 3 Ghz works better in rain and sea clutter		
4	Name minimum three features/controls of the radar that are important to optimize the radar picture	1. Gain - video gain 2. Rain- rain clutter control 3. Sea - sea clutter control 4. Puls length 5. Tune - tune control		
5	When do you use "rain clutter control" and "sea clutter control"?	1. Sea clutter control : Detect targets and objects through waves especially close to own ship 2. See targets and objects through rain		
6	What are the conditions for the "COLL alarm" to go off?	1. **Coll:** Collision alarm. One or more of the tracked targets are violating the CPA/TCPA limits.		
7	What is automatic acquisition	1. A pre determined area where radar targets are automatically tracked and AIS targets are activated.		
8	What is "fusing of target"	1. One vector will be presented on basis of 1 ARPA and 1 AIS target 2. Dependant of values set by operator		
9	What impact has antenna rotation speed on target detection? Advantages / Disadvantages	1. Slow = number of pulses on the target 2. Fast = faster update		

nr	Question **RADAR/AIS CAT 1, User level**	*"Model answers"*	Answer	%
10	Name at least 3 static and 3 voyage data?	1. MMSI 2. Call sign 3. Name 4. IMO number 5. Length and beam 6. Type of ship 7. Location of position fixing antennas on the ship 8. (Height over keel)		
		1. Ship's draught 2. Hazardous cargo type 3. Type of ship 4. Destination 5. ETA (number of persons on board)		
11	MMSI number is visual on an AIS track, but not the name. Why do you think this is?	1. Name is static data that is only transmitted every 6 min. 2. MMSI is with all the messages to identify the message		
12	When a target is tracked, does it show true and relative vectors?	1. True if in true modes (including NUP/FT) 2. Otherwise relative		

Nr	**Question: RADAR / AIS CAT 2, Technical, system understanding**	*"Model answers"*	Answer	%
	~~Why has a vessel two different nav radars (technically and with regards to performance)?~~ ~~Skjold class: Why is 9GHz band radar selected as the only radar.~~	*~~3 Ghz (10cm) og 9 Ghz (3 cm). X-Band (3 cm) S-Band (10 cm)~~* *~~Skjold: kortere bølgelengde bedre skilleevne, SART. Mindre antenne (3 Ghz er bedre på fog, rain, sea clutter)~~* 1. *~~Better target acquisition wrt X-band best on short range and S-band best on longer rangers.~~* 2. *~~Precipitation clutter: The effect is less marked at S-band (19 dB better than X-band for the same antenna beamwidths)~~* 3. *~~WRT Multipath: The lobing effect at S-band is at a different spatial frequency coarser) and therefore a ship with both S-band and X-band radars is unlikely to have a target nulled at both frequencies.~~* 4. *~~Different intereference thus the antennas is not place on the exact same place~~* a. *~~Target shielding different wrt blind arc.~~* 5. *~~Ability to track more targets with two sets~~*	(Merged with Q 3)	
13	Explain the tracking process?	1. Target or not target, permanent or moving 2. Target = yes. Calculate course and speed from point to point calculation, Rough large search area. 3. Navigation filter: accurate track based on more data. Reduces the search area. Courses are lagging behind when target turns 4. If the target is not found after a certain number of scan = lost track		

Nr	**Question: RADAR / AIS CAT 2, Technical, system understanding**	*”Model answers”*	Answer	%
14	“Radar AIS are complementary technologies that enhance the safety of navigation”. List the strengths and weaknesses of each technology to support this statement.	Radar vs AIS: 1. Rely on own system vs no control 2. Ship relative and sea stabilised vs SOG-COG 3. Difficult to jam vs easy to jam via GPS 4. Clutter vs no clutter 5. Line of sights vs behind obstacles 6. Lagging behind when speed/heading changes vs rapid update. 7. Only heading and speed vs lots of data		
15	How does automatic acquisition work?	1. A zone is designed around own ship 2. Targets entering zone will be automatically tracked 3. AIS targets entering will be activated 4. Can use barrier lines to avoid land		
16	Explain how rain-clutter control and sea-clutter control works, technically.	1. Sea: logarithmic adjustment of gain. Reducing gain more close to vessel 2. Rain: does not help with the reduction of gain. DIFF control cuts the echoes so that it is possible to see the target echo. Target echo or echo of land, etc., will in fact act in the same place every time we receive it, while reflection from rain will constantly change. Target echo will therefore be more powerful than the others.		
17	What are the tasks of the GPS receiver in the AIS?	1. Synchronizing transmission 2. Reserve position of the vessel		
18	Which sensors are connected to the radar?	1. Log 2. GPS 3. GPS Heading, 4. Gyro heading, 5. AIS 6. Echo sounder 7. Other		

Nr	**Question: RADAR / AIS CAT 2, Technical, system understanding**	*"Model answers"*	Answer	%
19	An AIS track with same name jumps from one echo to another. What could be wrong?	1. They have the same MMSI number (e.g.the Sjøbjørn of a CG)		
	Have you ever used automatic acquisition?	YES / NO		

Appendix D: Score calculations.

				SCORE	Mark	SCORE	Mark	SCORE	Mark	SCORE	Mark	SCORE	Mark	SCORE	Mark	SCORE	Mark	SCORE	Mark	SCORE	Mark	SCORE	Mark
				Off 1		Off 2		Off 3		Off 4		Off 5		Off 6		Off 7		Off 8		Off 9		Off 10	
Q	Q		MA Number of years navigator	4,5		0,8		8,0		3,0		1,5		0,8		5,0		2,0		2,0		0,7	
1	Explain how the mode NUP / FT ?	1	Land is moving.	1		0		1		0		0		0		0		1		0		0	
		2	Is confined to a square on the screen.	0		1		1		0		0		0		0		0		0		0	
		3	North up	1		1		1		1		1		1		1		1		1		1	
		4	Own pos fixed	1		1		1		1		1		1		1		1		1		1	
		5	True vector and trails.	1		1		1		1		1		1		1		1		1		1	
		6	Radar is not asigning trails on echoes that have opposite course and speed as own ship	0	67	0	67	0	83	0	50	0	50	0	50	0	50	0	67	0	50	0	50
2	Pros and cons of mode NUP / FT?	1	Depending good input log and gyro.	0		0		0		0		0		0		0		0		0		0	
		2	Easier to distinguish vessels from other echoes.	0		0		1		0		1		1		1		1		1		1	
		3	No need to reset own pos	1	33	0	0	1	67	1	33	0	33	0	33	0	33	1	67	1	67	1	67
3	How is 9 Ghz radar distinguished from 3 Ghz?	1	Shorter wavelength better resolution	0		0		1		1		1		1		0		1		1		1	
		2	Better target acg. Bettter on short rang	1		1		1		1		1		1		1		1		1		1	
		3	SART and Racon	1		1		0		0		0		0		0		1		1		1	
		4	Smaller antenna	0		0		0		0		0		0		0		0		0		0	
		5	3 Ghz is better regarding rain and sea clutter	0	40	0	40	0	40	0	40	0	40	0	40	1	40	0	60	0	60		75
4	Name minimum three features/ controls of the radar that are important to optimize the radar picture	1	Gain - video gain	1		1		1				1										1	
		2	Rain- rain clutter control	1		1		1		1		1		1		1		1		1		1	
		3	Sea - sea clutter control	1		1		1		1		1		1		1		1		1		1	
		4	Puls length							1		1		1		1		1		1		1	
		5	Tune - tune control (kan nevne pulslengde og tuning men tuning bør være i auto)		100		100		100	1	100	1	100	1	100		100		100	1	100	1	100
5	When do you use "rain clutter control" and "Sea clutter control"?	1	Sea clutter control : See targets and objects through waves especially close to own ship	1		1		1		1		1		1		1		1		1		1	
		2	See targets and objects through rain	1	100	1	100	1	100	1	100	1	100	1	100	1	100	1	100	1	100	1	100
6	What is the conditions for the "COLL alarm" to go off?	1	One or more of the tracked targets are violating the CPA/limits.	1		1		1		1		1		1		0		1		1		1	
		2	One or more of the tracked targets are violating the TCPA/limits	0	50	0	50	0	50	1	100	0	50	0	50	0	0	1	100	1	100	1	100
7	What is automatic acquisition	1	A pre determined area where radar targets are automatically tracked	1		1		1		1		1		1		1		1		1		1	
		2	A pre determined area where AIS targets are activated.	0	50	0	50	1	100	0	50	1	100	1	100	0	50	0	50	1	100	1	100
8	What is "Fusing of Target"		1) One vector will be presented on basis of 1 ARPA and 1 AIS target	0		0		1		1		0		1		0		0		1		0	
			2) Dependant of values set by operator	0	0	0	0	1	100	0	50	0	0	1	100	0	0	0	0	1	100	0	0
9	What impact has antenna rotation speed on target		1) Slow = number of pulses on the target	1		1		1		1		1		1		0,5							
			2) Fast = faster update	1	100	1	100	1	100	1	100	1	100	1	100	0	25						

				Mark	SCOR	Mark	Mark	SCORE	Mark	SCORE	Mark	SCORE	Mark	SCORE	Mark	SCORE	Mark	SCORE	Mark	SCORE	
				Off 11		Off 12		Off 13		Off 14		Off 15		Off 16		Off 17		Off 18		Off 19	
Q	Q		MA Number of years navigator	5,0		2,0		1,8		0,0		0,0		5,0		3		1		2	
1	Explain how the mode NUP / FT ?	1	Land is moving.	1		0		0						1		1		1		1	
		2	Is confined to a square on the screen.	0		0		0						1		0		0		1	
		3	North up	1		1		1						1		1		1		1	
		4	Own pos fixed	1		1		1						1		1		1		1	
		5	True vector and trails.	1		1		0						1		1		1		1	
		6	Radar is not asigning trails on echoes that have opposite course and speed as own ship	0	67	0	50	0	33					0	83	0	67	0	67	0	83
2	Pros and cons of mode NUP / FT?	1	Depending good input log and gyro.	1		0		0						1		0		0			
		2	Easier to distinguish vessels from other echoes.	1		1		1						1		1		0		1	
		3	No need to reset own pos	1	100	1	67	1	67					1	100	1	67	1	33	1	100
3	How is 9 Ghz radar distinguished from 3 Ghz?	1	Shorter wavelength better resolution	1		0		1		0		0		1		0		1		1	
		2	Better target acg. Bettter on short rang	1		1		1		1		1		1		1		0		0	
		3	SART and Racon	1		1		1		1		1		1		1		0		1	
		4	Smaller antenna	0		0		0		0		0		0		0		1		1	
		5	3 Ghz is better regarding rain and sea clutter	1	80	0	40	0	60	1	60	1	60	1	80	0	40	0	40	1	80
4	Name minimum three features/ controls of the radar that are important to optimize the radar picture	1	Gain - video gain	1		1						1				1		1		1	
		2	Rain- rain clutter control			1		1		1		1		1		1				1	
		3	Sea - sea clutter control	1		1		1		1		1		1		1				1	
		4	Puls length	1				1		1		1		1				1			
		5	Tune - tune control (kan nevne pulslengde og tuning men tuning bør være i auto)	1	100		100	1	100		100		100		100		100	1	100		100
5	When do you use "rain clutter control" and "Sea clutter control"?	1	Sea clutter control : See targets and objects through waves especially close to own ship	1		1		0,5		1		1		1		1		1		1	
		2	See targets and objects through rain	1	100	1	100	1	75	1	100	1	100	1	100	1	100	1	100	1	100
6	What is the conditions for the "COLL alarm" to go off?	1	One or more of the tracked targets are violating the CPA/limits.	1		1		1		1		1		1		1		1		1	
		2	One or more of the tracked targets are violating the TCPA/limits	1	100	0	50	0	50	1	100	1	100	1	100	1	100	1	100	1	100
7	What is automatic acquisition	1	A pre determined area where radar targets are automatically tracked	1		1		1		1		1		1		1		1		1	
		2	A pre determined area where AIS targets are activated.	0,5	75	0	50	0,5	75	1	100	1	100	1	100	0	50	1	100	1	100
8	What is "Fusing of Target"		1) One vector will be presented on basis of 1 ARPA and 1 AIS target	0		0		1		0		0		0		1		0		0	
			2) Dependant of values set by operator	0	0	0	0	1	100	0	0	0	0	0	0	1	100	0	0	0	0
9	What impact has antenna rotation speed on target		1) Slow = number of pulses on the target			1		1		1		1		1		1		1		1	
			2) Fast = faster update			1	100	1	100	0	50	1	100	1	100	1	100	1	100	0,5	75

Blue=FPR Red=Frigate Yellow = DO

Q	Q	MA Number of years navigator	Off 1	Mark	Off 2	Mark	Off 3	Mark	Off 4	Mark	Off 5	Mark	Off 6	Mark	Off 7	Mark	Off 8	Mark	Off 9	Mark	Off 10	Mark
		Years	4,5		0,8		8,0		3,0		1,5		0,8		5,0		2,0		2,0		0,7	
10	Name at least 3 static and 3 voyage data?	1) MMSI	1		1		1		1		1		1				1		1		1	
		2) Call sign													1							
		3) Name	1		1		1		1		1		1		1		1		1		1	
		4) IMO number																				
		5) Length and beam	1		1		1		1		1		1		1		1		1		1	
		6) Type of ship																				
		7) Location of position fixing antennas on the																				
		8) (Height over keel)																				
		1) Ship's draught			1		1		1		1		1		1		0		1		1	
		2) Hazardous cargo type																				
		3) Type of ship	0																			
		4) Destination	1		1		1		1		1		1		1		1		1		1	
		5) ETA	1		1		1		1		1		1		1		1		1		1	
		6) (Nr persons on board)		83		100		100		100		100		100		100		83		100		100
11	MMSI number is visual on an AIS track, but not the name. Why do you think this is?	1) Name is static data that is only transmitted every 6 min.	0	0	0	0	0	0	0	0	1	100	0	0	0	0	0	0	0	0	1	100
12	When a target is tracked, does it show True and	1) True if in true modes (including NUP/FT)	1		1		1		1		1		1		1		1		1		1	
		2) Otherwise relative	1	100	1	100	1	100	1	100	0	50	1	100	1	100	0	50	1	100	1	100
13	Explain the tracking process?	1) Target or not target, permanent or moving	1		1		1		0		1		1		1		0,5		1		1	
		2) Target = yes. Calculate course and speed from point to point calculation. Rough large search area.	0		0		1		1		1		0,5		0		0		0,5		1	
		3) Nav filter: accurate track based on more data. Reduces the search area. Courses are lagging behind when target turn	0		0		0		0		0		0		0		0		0		0	
		4) If the target is not found after a certain number of scan – lost track	0	25	0	25	0	50	0,5	58	0	50	0,5	50	0	25	0	15	0	58	0,5	65
14	"Radar AIS are complementary technologies that enhance the safety of navigation". List the strengths and weaknesses of each technology to support this statement.	1) Rely on own system vs no control	1		1		1		1		1		1		1		1		1		1	
		2) Ship relative and sea stabilised vs SOG-COG	0		0		0		0,5		0		0		0		0		0		0	
		3) Difficult to jam vs easy to jam via GPS	0		0		0		0		0		0		0		0		0		0	
		4) Clutter vs No clutter	0		0		0		0		0		0		0		0		0		0	
		5) Line of sights vs behind obstacles	0		1		1		1		1		1		1		1		1		1	
		6) Lagging behind when speed/heading changes vs rapid update.	0		0		1		0		1		0		0		0		0		0	
		7) Only Heading and speed vs lots of data	0	14	1	43	1	57	0	36	1	57	0	29	0	29	1	43	1	43	1	43
15	How does automatic acquisition work?	1) A zone is designed around own ship	0		1		1		1		1		1		0		1		1		1	
		2) Targets entering zone will be auto tracked	0		1		1		1		0		1		0		1		1		1	
		3) AIS targets entering will be activated	0		0		1		0		0		0		0		0		0		0	
		4) Can use barrier lines to avoid land	0	0	0	50	1	100	0	50	0	25	1	75	0	0	1	75	1	75	1	75
16	Explain how Rain-rain clutter control and Sea - sea clutter control works, technically.	1) Sea: logarithmic adjustment of gain. Reducing gain more close to vessel	0		0		0,5		1		1		0		0		1		1		1	
		2) Rain: does not help with the reduction of gain. DIFF control cuts the echoes so that it is possible to see the target echo. Target echo or echo of land, etc., will in fact act in the same place every time we receive it, while reflection from rain will constantly change. Target echo will therefore be more powerful than the others.	0	0	0	0	0	25	0	50	0	50	0	0	0	0	0,5	75	0	50	0	50
17	What is tasks of the GPS receiver in the AIS?	1) Synchronizing transmission	0		0		0		0		0		0		0		0		0		0	
		2) Reserve position of the vessel	0	0	1	50	0,5	25	1	50	1	50	1	50	0,5	25	0	0	1	50	0	0
18	Which sensors are connected to the radar?	1) Log	1		1		1		1		1		1		1		1		1		1	
		2) GPS	1		1		1		1		1		1		1		1		1		1	
		3) GPS Heading,	0		0		1		1		1		1		0		0		0		0	
		4) Gyroheading,	0		0		1		0		1		1		0		1		0		1	
		5) AIS	0		0		1		1		0		1		0		0		0		1	
		6) Echosounder	0		0		0		0		0		0		0		0		0		0	
		7) Other		33		33		83		67		67		83		33		50		33		67
19	An AIS track with same name jumps from a echo to another. What could be wrong?	1) They have the same MMSI number (e.g.the sjøbjørn of a CG)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Have you ever used automatic acquisition	YES / NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Q	Q	MA Number of years navigator	Off 11	Mark	Off 12	Mark	Off 13	Mark	Off 14	Mark	Off 15	Mark	Off 16	Mark	Off 17	Mark	Off 18	Mark	Off 19	SCORE
		Years	5,0		2,0		1,8		0,0		0,0		5,0		3		1		2	
10	Name at least 3 static and 3 voyage data?	1) MMSI	1		0		1		1		1		1		1		1		1	
		2) Call sign													1				1	
		3) Name	1				1		1		1		1				1		1	
		4) IMO number			1				1		1		0		1					
		5) Length and beam	1		1		0										1			
		6) Type of ship																		
		7) Location of position fixing antennas on the																		
		8) (Height over keel)																		
		1) Ship's draught	1		1		1		1		1		0							
		2) Hazardous cargo type																		
		3) Type of ship													1		1		1	
		4) Destination	1		1		1		1		1		1		1		1		1	
		5) ETA	1		1		1		1		1		1		1		1		1	
		6) (Nr persons on board)		100		83		83		100		100		67		100		100		100
11	MMSI number is visual on an AIS track, but not the name. Why do you think this is?	1) Name is static data that is only transmitted every 6 min.	0	0	0	0	0	0	0	0	1	100	0	0	0	0	0	0	0	0
12	When a target is tracked, does it show True and	1) True if in true modes (including NUP/FT)	1		1		1		1		1		1		1		1		1	
		2) Otherwise relative	1	100	1	100	1	100	1	100	1	100	1	100	1	100	1	100	1	100
13	Explain the tracking process?	1) Target or not target, permanent or moving	0,5		0,5		1		1		1		1		0		1		1	
		2) Target = yes. Calculate course and speed from point to point calculation. Rough large search area.	0		0		0		0		0		1		1		1		1	
		3) Nav filter: accurate track based on more data. Reduces the search area. Courses are lagging behind when target turn	0		0		0		0		0		0		0		0		0	
		4) If the target is not found after a certain number of scan – lost track	0	15	0	15	0	25	0	25		55	0	50	0	25	1	75	1	75
14	"Radar AIS are complementary technologies that enhance the safety of navigation". List the strengths and weaknesses of each technology to support this statement.	1) Rely on own system vs no control	1		1		1		1		1		1		0		1		0	
		2) Ship relative and sea stabilised vs SOG-COG	0		0		0		0		0		0		0		1		0	
		3) Difficult to jam vs easy to jam via GPS	0		0		0		0		0		0		0		0		1	
		4) Clutter vs No clutter	0		0		0		0		0		0		0		0		0	
		5) Line of sights vs behind obstacles	1		1		1		1		1		1		1		0		1	
		6) Lagging behind when speed/heading changes vs rapid update.	0		1		1		1		0		0		1		1		0	
		7) Only Heading and speed vs lots of data	1	43	1	57	1	57	1	57	1	43	1	43	1	43	1	57	0	29
15	How does automatic acquisition work?	1) A zone is designed around own ship	1		0		1		1		1		1		1		1		1	
		2) Targets entering zone will be auto tracked	1		0		1		1		1		0		1		1		1	
		3) AIS targets entering will be activated	0		0		0		0		0		0		0		0		0	
		4) Can use barrier lines to avoid land	1	75	0	0	1	75	0	50	0	50	0	25	1	75	0	50	0	50
16	Explain how Rain-rain clutter control and Sea - sea clutter control works, technically.	1) Sea: logarithmic adjustment of gain. Reducing gain more close to vessel	0		1		1		1		1		0,5		1		1		0,5	
		2) Rain: does not help with the reduction of gain. DIFF control cuts the echoes so that it is possible to see the target echo. Target echo or echo of land, etc., will in fact act in the same place every time we receive it, while reflection from rain will constantly change. Target echo will therefore be more powerful than the others.	0	0	0,5	75	0	50	0	50	0	50	0	25	0,5	75	0,5	75	0	25
17	What is tasks of the GPS receiver in the AIS?	1) Synchronizing transmission	0		0		1		1		0		1		1		0		0	
		2) Reserve position of the vessel	0,5	25	0,5	25	0,5	75	1	100	1	50	1	100	0	50	1	50	1	50
18	Which sensors are connected to the radar?	1) Log	1		1		1		1		1		1		1		1		1	
		2) GPS	1		1		1		1		1		1		1		1		1	
		3) GPS Heading,	0		0		1		1		0		1				1		1	
		4) Gyroheading,	1		1		1		1		0		1		1		1		1	
		5) AIS	1		1		1		1		0		1		1		1		1	
		6) Echosounder	0		0		0		0		0		0		0		0		1	
		7) Other		67		67		83		83		33		83		80		83		100
19	An AIS track with same name jumps from a echo to another. What could be wrong?	1) They have the same MMSI number (e.g.the sjøbjørn of a CG)	0	0	0	0	0	0	1	100	0	0	0	0	0	0	0	0	1	100
20	Have you ever used automatic acquisition	YES / NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	

Appendix E: Observation form

Form nr 1: Live sailing. Make note of the operation of radar, mostly adjustments and with regards to targets

Time	Area	Day/ Night	Level of difficulty	Functions used on the radar and IBS	Duration	Remarks

Form nr 2: Forms for live sailing: NOT performed activity. E.g. : Adjusting gain, sea, scale, pulse, no tracking of targets. Sea or ground stabilized input. Assessment of the course and speed.

Time	Area	Day Night	Level of difficulty	Functions NOT used	Why should it be used	Remarks

Appendix F: Skjold class fast naval craft and Fridtjof Nansen class frigate.

Figure 7-4: Skjold class, 45 metres – max 60 knots (source, www.forsvaret.no)

Figure 7-5: Skjold class IBS (Kongsberg, 2005)

Figure 7-6: Fridtjof Nansen class, 134m, max 26 knots (source, www.forsvaret.no)

Figure 7-7: IBS Fridtjof Nansen class (Kongsberg, 2005)