DEPARTMENT OF CIVIL ENGINEERING

NOTTINGHAM GEOSPATIAL INSTITUTE

CONTROL OF POSITION SENSOR INPUT TO ECDIS ON HIGH SPEED CRAFT

AUTHOR	**ODD SVEINUNG HAREIDE**
SUPERVISORS	**PROF ANDY NORRIS**
	DR CHRIS HILL
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Abstract

By 2018 all larger ships are to be equipped with Electronic Chart Display and Information System (ECDIS). The paradigm shift from paper charts to electronic charts has been a technological leap for mariners, and the Integrated Navigation Systems (INS) are getting more and more complex. This leads to new challenges for the navigators of today.

Global Navigation Satellite Systems (GNSS) such as GPS are the primary position sensor input for ECDIS, and it has since its early beginning in the middle of the 1990s been very reliable. National and worldwide statistics show that there has been a slight increase in navigational accidents since the introduction of ECDIS, but the reasons for this is not clear. In the literature review it is laid down that position sensors have its potential fault, and GNSS and its augmentation systems is described to better understand its advantageous and limitations. Control of ECDIS with position control methods are explored, and divided into two methods of control: Visual- and Conventional methods.

Through field work, simulator tests and interviews the findings are clear. The navigators of today rely too much upon their primary position sensor which normally is a GNSS such as GPS. A questionnaire reveals that the navigators have insufficient deeper system knowledge of the navigation aids in use. This can lead to a potentially serious accident with loss of lives and large environmental damage. To achieve safe navigation it is important to continuously conduct control of primary position sensor input to ECDIS with a secondary position sensor by visual- and/or conventional control methods. The advantages and limitations with the different methods of control are discussed. Position sensors such as GNSS can fail, and navigators of today and tomorrow need to monitor the position sensor input to ECDIS with other means than GNSS.

Acknowledgement

First of all I would like to express my gratitude for all the positivity that has met me while working with this research project. It has become clear that the development of the craftsmanship of navigation, and especially within the field of ECDIS, is something that many think of and want to have a say in. Thanks to many colleagues for enthusiastic and constructive discussion on this matter (none mentioned, none forgotten).

An extensive field work has taken place, and it would not be possible without the warm welcome and the open mind of people at the Norwegian Corvette Service and the Navigation Centre at the Royal Norwegian Navy. A special thanks to the simulator department at the Navigation Centre, for setting up and facilitating the simulator tests. The staff and crew of ship owner NorLeds catamarans have also given me a warm welcome on board during the data collection.

During supplementary work with the research project, I have had meetings with scholars at Vestfold University College and Aalesund University College department of nautical engineering. This has been valuable and much appreciated feedback to the project.

Prof Andy Norris has provided guidance and interesting thoughts on the challenges I have encountered while writing this thesis. Dr Chris Hill has been supervising the project from the University of Nottingham, and I thank them for their feedback.

Finally I would like to express gratitude to my beloved family, Tone and Lilly, for their patience and support during this work.

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Abbreviations

6NK – Sixth semester Navigation Course

AIS – Automatic Identification System

ARP – Arm Rest Panel

AUC – Aalesund University College

CATZOC – Category of Zones of Confidence

CO – Commanding Officer

DGPS – Differential Global Positioning System

DNV – Det Norske Veritas

EBL – Electronic Bearing Line

ECDIS – Electronic Chart Display and Information System

ECS – Electronic Chart System

EGNOS – European Geostationary Navigation Overlay System

eLORAN – Enhanced Long Range Navigation

ENC – Electronic Navigation Chart

ETA – Estimated Time of Arrival

FD – Fault Detection

FDE – Fault Detection and Extraction

FPB – Fast Patrol Boat

GBAS – Ground Based Augmentation System

GNSS - Global Navigation Satellite System

GPS – Global Positioning System

HMI – Human Machine Interface

HNoMS – His Norwegian Majesty`s Ship

HSC – High Speed Craft

IBS – Integrated Bridgde System

IHO – International Hydrographic Organization

IMO – International Maritime Organization

INS – Integrated Navigation System

INaS – Inertial Navigation Sensor

ITU – International Telecommunication Union

KTS – Knots (1knot = 1nm/hour)

LORAN – Long Range Navigation

MFA – Ministry of Foreign Affairs

MFD – Multi Function Display

MoD – Ministry of Defence

MTBT – Norwegian Corvette Service Training Centre

MTBV – Norwegian Corvette Service

NNC - The Royal Norwegian Navy Navigation Centre

NM – Nautical Mile (1nm = 1852metres)

OBD – Optical Bearing Device

ODGPS – Ordinary Differential Global Positioning Service

OOW – Officer Of the Watch

PI – Parallel Index

PPS – Precise Positioning Service

RADAR – RAdio Detection And Ranging

RAIM – Receiver Autonomous Integrity Monitoring

RIB – Rigid Inflatable Boat

RNC – Raster Navigation Chart

RNoN – Royal Norwegian Navy

RNoNA – Royal Norwegian Naval Academy

SBAS – Space Based Augmentation System

SENC – System Electronic Navigation Chart

SNK – Skjold Navigation Course

SOA – Speed Of Approach

SOLAS – Safety Of Life At Sea

SPS – Standard Positioning Service

SVK – Skjold Officer of the Watch Course

UTC – Coordinated Universal Time

VRM – Variable Range Marker

VUC – Vestfold University College

UoN – University of Nottingham

WAAS – Wide Area Augmentation System

WADGPS – Wide Area Differential Global Positioning System

XTE – Cross Track Error

ZOC – Zones of Confidence

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1.0 Introduction

1.1 Background

By the year 2018 all larger ships are to be equipped with Electronic Chart and Display Information System (ECDIS) (IMO, 2009). This has led to a paradigm shift from paper charts towards Electronic Charts and Integrated Navigation and Bridge Systems (INS/IBS). With this paradigm shift there will be navigators of today and navigators of tomorrow, with different knowledge and different perspective of what is important in their daily work as an Officer Of the Watch (OOW) on board a vessel.

The author has his background from The Royal Norwegian Corvette Service (MTBV), from both the Hauk-Class[1] and the Skjold-Class[2] Fast Patrol Boats (FPB). Even though the two classes of ships are products of different times, there are many similarities in their operational pattern. Both are high speed craft (HSC), operating primarily along the Norwegian coast. The Norwegian coast is known for its harsh and challenging environment, both with regards to weather but also due to a large number of islands and skerries. With 6 years of experience as a navigator on board Norwegian FPBs the author has experience from both paper charts and ECDIS.

When converting from paper charts to ECDIS, a new world within the field of navigation had to be explored. This is still a path which is not well defined, and there are still findings and developments that refine the world of ECDIS. This will also be the case in the years to come. There has been a large leap in the right direction since the first passages with an ECDIS in the middle of the 1990s until the way it is done today. Nevertheless, the refinement of ECDIS is not done yet.

The Royal Norwegian Naval Academy Navigation Centre (NNC) is a centre of excellence within navigation in the Royal Norwegian Navy (RNoN). The author has his work at NNC with navigation systems and education of cadets in navigation and in the use of ECDIS.

The navigators fresh out of school today are accused of being a product of the "computer generation", whose main problem is using more time looking at the

[1] For further information about the Hauk-Class: http://en.wikipedia.org/wiki/Hauk-class_patrol_boat
[2] For further information about the Skjold-Class: http://www.naval-technology.com/projects/skjold/

computer screen than looking out the window of the bridge (Norris, 2010). Control of position sensor input to ECDIS is a term which has appeared (NNC, 2012, MTBTS, 2009, Norris, 2013a), and navigation teams are trained in this control method. The different ways of continuously controlling the position sensor input to the ECDIS provide the navigators with a toolbox for safe navigation, and also keep the navigators` eyes up and facing forward in the direction the craft is sailing. This method addresses both problems of (1) controlling the ECDIS and (2) keeping the navigators` attention out through the windows of the bridge and away from the screens on the bridge. All of the systems in an INS is crucial to monitor, but all these screens also lead to information overload and excessive workload for the navigator (Norris, 2010). Correct use of the systems and a good look-out are of high importance to enhance safe navigation.

ECDIS first arrived in the middle of the 1990s, and the move from paper chart to electronic chart has been a big move within the field of marine navigation. Both the author and many in the nautical community have had a feeling that there has become a knowledge gap when introducing this new technology to the marine world. The author has experience from HSC using both paper and electronic charts, and has been a part of this paradigm shift from paper to electronic charts. Through observations there has been identified a knowledge gap when moving from paper charts to the use of electronic charts and ECDIS-systems. This has evolved to writing this research thesis where further observations on board military and civilian HSC and tests in a controlled environment have taken place. Findings from this project aim to help future navigators to efficient and safe use of ECDIS when it comes to controlling the position sensor input. The research will also provide navigators with a toolbox of different control methods which will ease their work as an OOW in their daily work.

1.2 Research Focus

The focus of the research will be within the control methods of position sensor input chosen to ECDIS. Control methods are divided into visual and conventional control of ECDIS, which will be explained later on in the thesis. The platform of research will be high speed craft in littoral waters.

The reason for this focus is the fact that the position sensor input to ECDIS is primarily Global Navigation Service Systems (GNSS) such as Global Positioning System (GPS). This is a system with high reliability (Hofmann-Wellenhof, 2008), but it is possible that such a system can fail (Elliott D. Kaplan, 2006, Engineering, 2011). There are also areas of the world where the coverage of such systems are poor. Especially in the High North, which Norway is a part of, there are problems towards the reliability and coverage of GNSS with and without augmentation systems such as EGNOS and WAAS (Kjerstad, 2009). It is therefore fundamental that ECDIS is continuously monitored so that if a situation occurs where GNSS is degraded, this is known by the navigators and the passage can continue with other available means.

The research will be divided into *two* main parts:

1. *Literature review*
2. *Field study*. The field work will be divided into *three* subsections:
   I. Field study on board military and civilian HSC.
      a) Conduct observations of which control methods are used in controlling position sensor input to ECDIS.
   II. Simulator test.
      a) To explore and measure if navigators are controlling the position sensor input to the ECDIS, and to disclose how much time is needed for the OOW to detect position errors from the GNSS.
   III. Interviews with navigators.
      a) Part 1: Used as a brainstorming to examine what navigators find efficient when it comes to control of position sensor input to ECDIS, and two short questions with regards to system knowledge in relation to ECDIS.
      b) Part 2: Questionnaire to examine system knowledge amongst navigators (in collaboration with fellow student Steinar Nyhamn (2013)).

1.3 Research Aim and Individual Research Objectives

1.3.1 Research Aim

How to improve and develop the control of position sensor input chosen to ECDIS on a High Speed Craft in littoral waters.

1.3.2 Research Objective

The overall aim of this research is to understand the transition from paper charts to electronic charts, and examine if the control methods of the position sensor used by navigators of today are sufficient with the demands that evolved in the shift from paper charts to electronic charts and the use of ECDIS. This implies if position control methods used on paper charts can be used on ECDIS, and expedient use of new technological aids available on the bridge in an Integrated Navigation System.

1. *Identify* control methods made for the use of ECDIS on an HSC (literature and field study).
2. *Examine* teams onboard HSC, and the control methods of position sensor input to the ECDIS in use (field study).
3. *Evaluate critically* different teams in a controlled environment (simulator) to see how position sensor input to ECDIS is controlled.
4. *Explore* the system knowledge and “best-practice” of navigators on board HSC (interviews and questionnaire).
5. *Formulate* recommendations on methods of control of position sensor inputs to the ECDIS on an HSC.

1.4 Value of the Research

With the paradigm shift from paper charts to electronic charts and the use of ECDIS, it has been stated that there is a gap that has evolved when it comes to knowledge of the systems and how to control the position sensor input to ECDIS (Kjerstad, 2003, Norris, 2010). Scholars inquire more research and concrete material from research which they can refer to in their education of new navigators and ECDIS operators. The research done in this thesis will contribute to fill parts of this gap, and will examine if system knowledge regarding ECDIS amongst navigators is at a sufficient level. Parts of this project is meant to be a guidance for navigators onboard HSC in littoral waters on what methods there are to control the position sensor input to the ECDIS, and what are their advantages and limitations. This will include both visual and conventional methods of control. It will also be used in a future revision of “Electronic charts: Guidelines and recommendations for the Norwegian Navy” (NNC, 2007). The conclusions of the thesis will be distributed to all participants (civilian and military) who have taken part in the research, which can be implemented into their manuals and procedures.

1.5 Outline Structure

Chapter 1 Introduction: A brief introduction is given on the subject. This is divided into background, research focus, research aim and objectives and value of the research.

Chapter 2 Literature review: Covers regulations and legislation with regards to ECDIS, and definitions are laid down. ECDIS, position sensor input such as GNSS and its augmentation systems are explained briefly. Control methods of ECDIS are discussed and visual and conventional methods of control are explained, with the importance of a well thought out human machine interface to conduct the described control methods and decrease workload and performance stressing factors for the navigator.

Chapter 3 Research methods: Briefly states the limitations of the thesis. The research will be divided into two main parts: Literature review given in chapter 2 and a field study. The field study is divided into three subsections: Field work on board military and civilian HSC, simulator tests and interviews and questionnaire. The chapter ends with an analysis of the validity and reliability of the field study.

Chapter 4 Findings: Consists of a description and analysis of the observations done on board civilian and military HSC, in the simulator test and from the interview and questionnaire. This is summed up in a synthesis of findings at the end of this chapter.

Chapter 5 Conclusion: The conclusion from the thesis is given in chapter 5, with a subsection of conclusions to each research objective from Chapter 1. It comprises recommendations for future work, and a short summary of conclusions.

All chapters start with a short summary of the thesis so far and an introduction to the chapter, and end with a short summary of the work done in the relevant chapter.

2.0 Literature review

The field of control of position sensor input to ECDIS in Littoral HSC is a narrow domain, and there is not much literature on this specific matter. However, there is much literature on pieces of my research aim, and the goal of my literature review has been to explore broadly on the matter of position sensor control with ECDIS and its use in HSC. Visual control has been the backbone of a navigator's art for years, and most methods used on paper charts can be adapted to ECDIS. ECDIS is a large technological leap in navigation, and it is important that all aspects of control of ECDIS are highlighted. If an engineer asks a navigator what he expects of the future, he will make small adjustments to the equipment which he knows and uses in his day to day work (Norris, 2013a). It can be difficult for a navigator on board a high speed ship using an ECDIS to see what means to use for control, and that is why the literature review is essential to highlight all these means and pitfalls in the use of ECDIS. Starting off with regulations, and continuing along the path of ECDIS, navigational accidents and statistics with regards to the implementation of ECDIS, position sensor inputs, integrity, control of ECDIS, Human Machine Interface (HMI) and performance shaping factors (PSF) to investigate and distinguish the advantages and limitations in the use of ECDIS.

The International Maritime Organization (IMO) regulates the use of ECDIS, and a distinction between regulations and literature has been made.

2.1 Regulations

IMO is the United Nations organization that handles all matters regarding navigation and maritime transport. In 1974 *The Convention of Safety of Life at Sea* (SOLAS) was issued and adopted by the member states of the United Nations (IMO, 1974). Especially chapter V of SOLAS, *Safety of Navigation*, specifies the requirements for the navigational equipment to be used on board ships entitled to fly the flag of a party to the SOLAS Convention. IMO Member States are obliged to adopt IMO rules and regulations, such as those in SOLAS, into their national legislation. However, only when the requirements of the Convention have been incorporated into national legislation they affect the individual ships registered by that State.

In 2009 the amendment for Regulation 19 for ECDIS in SOLAS chapter V was put into force, stating that all larger vessels should have and use ECDIS within 2018. This is shown in figure 2.1 below (Scholey, 2010).

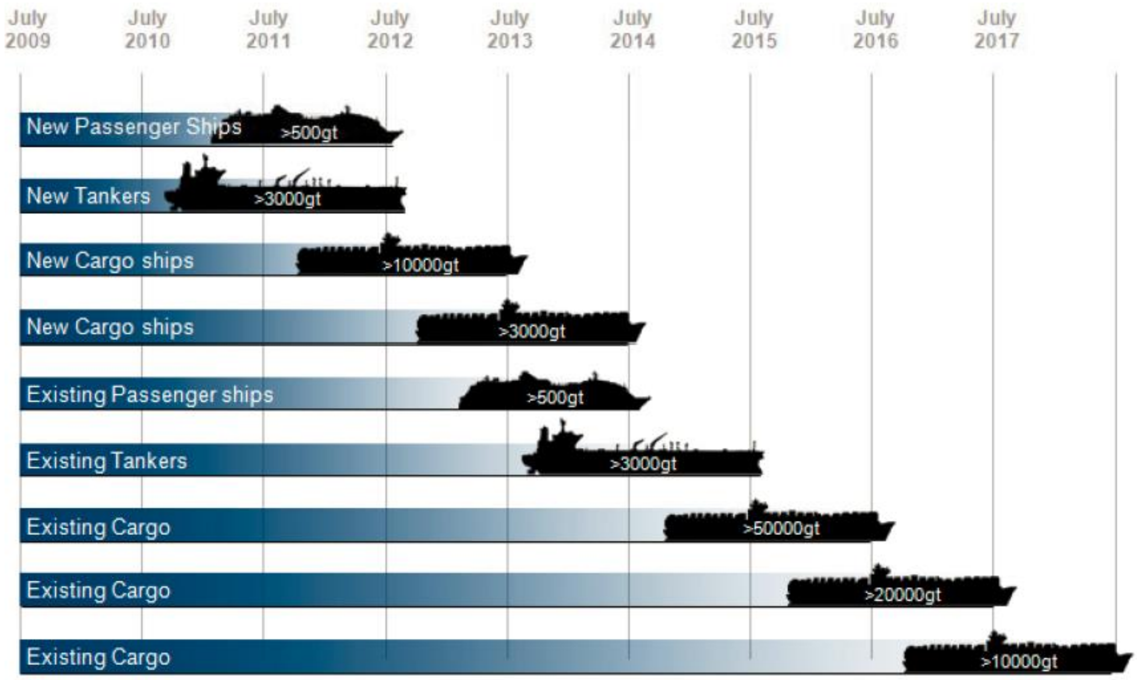

Figure 2.1 ECDIS implementation

When it comes to HSC, Paragraph 13.8.2 of High-speed craft (HSC) Code, 2000, details the SOLAS carriage requirements for HSC, which shall be fitted with an ECDIS as follows:

- craft constructed on or after 1 July 2008;
- craft constructed before 1 July 2008, not later than 1 July 2010.

The above implies that all HSC are fitted with an ECDIS.

In Norway it is mandatory with an HSC course, with reference to NOU 1994:9. The course is divided into two main parts. Part one consisting of Crew Resource Management (CRM), and part two consisting of a technical/operational course (MFA, 1994).

When it comes to training requirements, IMO Model Course 1.27 *"Operational use of ECDIS"(IMO, 2012)* is adopted to address the training of navigators in the use of ECDIS.

It is divided into 5 areas with 37 topics totalling 40.0 hours. IMO Model Course 1.27 has two fundamental definitions in it; *Generic ECDIS Training* and *familiarisation.*

> *Generic ECDIS Training: ECDIS training to ensure that navigators can use and understand ECDIS in the context of navigation and can demonstrate all competencies contained in and implied by STCW 2010. Such training should ensure that the navigator learns to use ECDIS and can apply it in all aspects of navigation, including the knowledge, understanding and proficiency to transfer that skill to the particular ECDIS system(s) actually encountered on board, prior to taking over navigational duties. This level of training should deliver the competencies at least equivalent to those given in Model Course 1.27 (IMO, 2012).*

> *Familiarisation: Following the successful demonstration of competencies contained in the Generic ECDIS Training, familiarisation is the process required to become familiar with any onboard ECDIS (including backup) in order to assure and demonstrate competency onboard any specific ship's ECDIS installation, prior to taking charge of a navigational watch (IMO, 2012).*

The thesis will also address the use of RADAR when controlling the ECDIS. The RADAR carriage requirements are defined by IMO in the SOLAS Convention Chapter V Regulation 19 (IMO, 2002). It states that all ships of 300 gross ton (GT) and upwards and passenger ships of any size will be fitted with *a 9 GHz radar, or other means, to determine and display the range and bearing of radar transponders and of other surface craft, obstructions, buoys, shorelines and navigational marks to assist in navigation and collision avoidance (IMO, 2002).* There are also rules for vessels above 3000 GT, but this is outside the limitations of this thesis.

2.1.1 Definitions

IMO defines ECDIS in the Performance standards for ECDIS (IMO, 2012):

> *Electronic chart display and information system (ECDIS) means a navigation information system which, with adequate back-up arrangements, can be accepted as complying with the up-to-date chart required by regulation V/20 of*

the 1974 SOLAS Convention, by displaying selected information from a system electronic navigational chart (SENC) with positional information from navigation sensors to assist the mariner in route planning and route monitoring, and by displaying additional navigation-related information if required.

HSC refers to a class of vessels that are characterised by the combination of light ship constructions and the ability to maintaining manoeuvre abilities while holding high speed. The formal definition states that a high-speed craft is a craft capable of maximum speed, measured in meters per second (m/s), equal to or exceeding $3.7\nabla^{0.1667}$. Where ∇ = Volume of displacement corresponding to the design waterline (m^3)[3] (IMO, 2008). Design waterline is defined as the waterline corresponding to the maximum operational weight of the craft with no lift or propulsion machinery active. Further is a passenger craft defined as a craft carrying more than 12 passengers (Kjerstad, 2003). All the vessels used in this thesis, both in the literature review and in the field study, fulfil the requirements of Kjerstad`s definition.

Navigation in littoral waters (Mann, 2000) is defined as navigation in the inlets, along the coastline, inside the coastline and within sight of land. Distinguishing marks are skerries, underwater rocks and it is a very difficult environment due to the close proximity of land. There is no single definition of littoral waters. One example of this is the vast Norwegian coastline.

Efficient navigation is defined as (NNC, 2012):

The vessel is operating in an optimal way compared to the mission it is executing.

- *In the waters the vessel is designed for (keeping good speed).*
- *With the speed necessary for reaching the aim.*
- *Constant assessment of the vessel`s opportunities and limitations.*

This is a military definition, but can also adhere to an HSC in passenger traffic which aim is to maintain its schedule and conduct a safe passage.

[3] The speed represented by the formula but expressed in knots is $7.192\ \nabla^{0.1667}$

When it comes to integrity monitoring of ECDIS, both Weintrit (2009) and Norris (2010) write how this could be done by different types of integrity monitoring aids. This could be divided into two sections in general, and the author has made a definition which is used throughout the thesis:

Visual control is defined by the author as making observation with the aid of visual sights, such as the traditional cross fix with several lines of position. These observations can be transferred to the ECDIS through different types of interface.

Conventional control is defined by the author as comparing two (or more) systems or sensors to conduct an integrity check to validate the position on the ECDIS by different types of interface. This can be done by e.g. AIS and RADAR. An example of this is radar overlay (correlation of radar return on conspicuous objects with charted position). These observations can be transferred to the ECDIS, and is commonly integrated in the INS. Both visual control and conventional control will be further discussed and explained in the literature review.

Paradigm shift if defined by the author as the transition between paper charts and electronic charts used in an ECDIS, and will be used and referred to throughout the thesis. The author substantiates this paradigm shift with IMO`s Manila Conference in 2010. IMO defines the navigation at operation level of this paradigm shift in STCW, 2010, Table AII/1: *"Maintain the safety of navigation through the use of ECDIS" (IMO, 2010, page 32).* It is shown with this table that IMO underlines the importance of electronic systems of position fixing and navigation.

2.2 Literature

In the following part of the literature review, there will be an introduction to the ECDIS, and how it presents a paradigm shift for navigators. It is presented with national and worldwide statistics how ECDIS may have had influence on navigation accidents. Further ECDIS and its position sensor inputs such as GNSS, augmentation systems and DGPS are explained. When it comes to integrity checks and control of position sensor input, visual and conventional control methods are laid down and the importance of integrity checks underlined. RADAR and AIS are two important aids in conventional control and their functioning is described briefly. It is also crucial that the navigators are familiar with the specific ECDIS system they use, and at the end human machine interface in the use of ECDIS is presented.

2.2.1 Introduction of ECDIS

With the introduction of GPS in maritime use in the 1990s with the interface to ECDIS around 1995 (Kreutzer, 2010), a new era of navigation started. The appearance of computers on the bridge of a ship revolutionised the way of navigation, and is a very good aid if used correctly (Norris, 2010). With the introduction of a new technological aid such as the ECDIS, it might be tempting to say that this aid has made the seaways of today safer, but both national and worldwide statistics indicate the opposite (Figure 2.2, 2.3 and 2.4). The national statistics show that ship accidents decreased from 2000 until 2004, but have increased again after 2004 and are at approximately the same level today as in the year 2000 in Norway (Directorate, 2011).

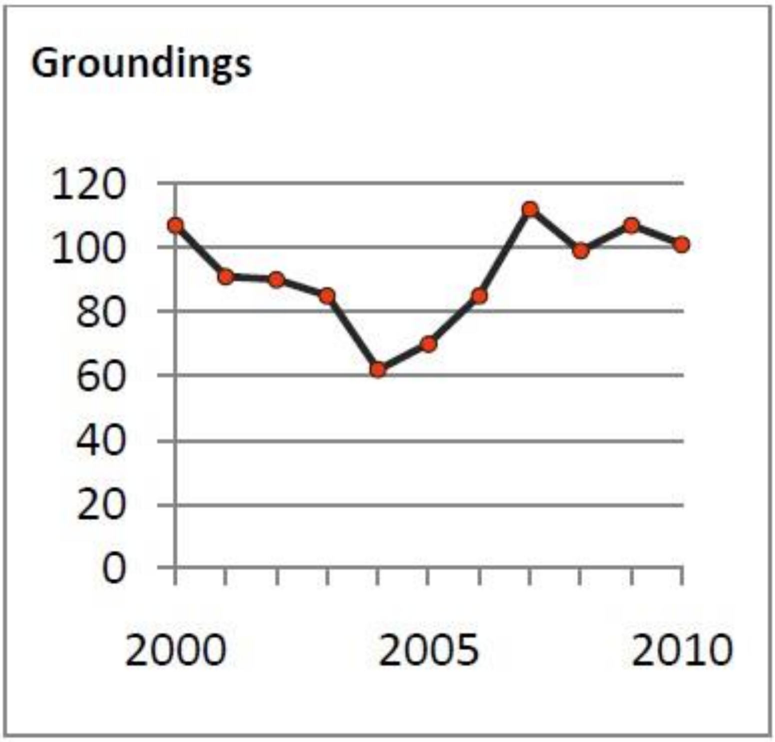

Figure 2.2 Ship accidents 2000-2010

Grounding means any contact between the vessel and the seabed. No distinction is made between grounding or ground contact. Grounding is recorded as an accident even when damage to the vessel is very limited (Directorate, 2011). The data from the Norwegian Maritime Directorate (2011) does not include a report which states each individual grounding and its causes. The statistics needs further break down to category of ship, to see the effect on grounding statistics for example with HSC after the time of mounting and starting to use the ECDIS. These statistics have not been found, and this can thus only be seen as a trend and needs further investigation. Note that all larger vessels are to implement and use ECDIS by 2018, so the statistics from 2018 would be of interest to analyse.

The reason for the increase in groundings since 2004 is not clear, but given that the utilization of each ship is equal and the percentage in reports of accidents is unchanged, there is reason to believe that the increased number of accidents indicates an increased risk of an accident happening (Directorate, 2011). The causal explanations were originally based on simple theories where the relationship between the actual damage caused by the accident and triggering factors was direct and easily identifiable. It was usually believed that the cause was human or technical failure, and the person directly involved, for example, the master of the ship, was assigned the criminal responsibility (Directorate, 2011).
In recent years other explanatory models have been developed that emphasize an understanding of systems, taking into account various factors that affect the actor in the technical or organizational system of which he or she is a part (Røed-Larsen, 2004). One decisive system in this organization is the ECDIS and its use in an Integrated Bridge System[4] (IBS).

Looking into the worldwide statistics from Information Handling Service (IHS) Fairplay (IHS, 2013), we see a slightly different trend. Looking at Figure 2.3, the total amount of serious accidents has risen since 1995, and looking at Figure 2.4, the percentage of distribution of navigational versus non-navigational accidents is slightly increased in the same period. This could imply that the navigation related accidents have risen in frequency since 1995 and the start of the ECDIS era. It does not say anything of this being the ECDIS` fault, but it shows that with the introduction of ECDIS the amount of navigational accidents did not drop significantly.

[4] An integrated bridge system (IBS) is defined as a combination of systems which are interconnected in order to allow centralized access to sensor information or command/control from workstations, with the aim of increasing safe and efficient ship's management by suitably qualified personnel.

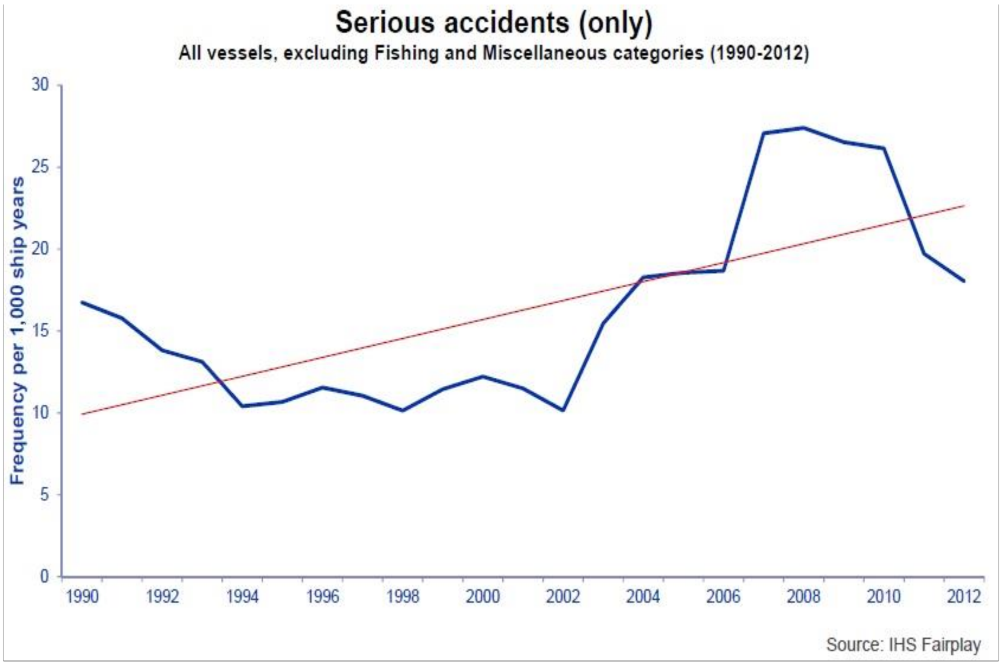

Figure 2.3 Serious accidents statistics

In this period of time (1995-2012) the ECDIS has been implemented, and the increase in serious accidents might suggest that it could have something to do with the use of ECDIS. From figure 2.4 there is also an increase in the distribution between navigational and non-navigational accidents, which indicates that something is causing a relative increase in navigation accidents. This is outside the scope of this thesis, and needs further investigation to analyse the statistics and conduct further research in this matter. The statistics used in this thesis is thus to show a trend, and make the reader aware of that even though ECDIS is known to be a good navigation aid for the navigator (Weintrit, 2009), it must be used the correct way to enhance safe navigation (Norris, 2010).

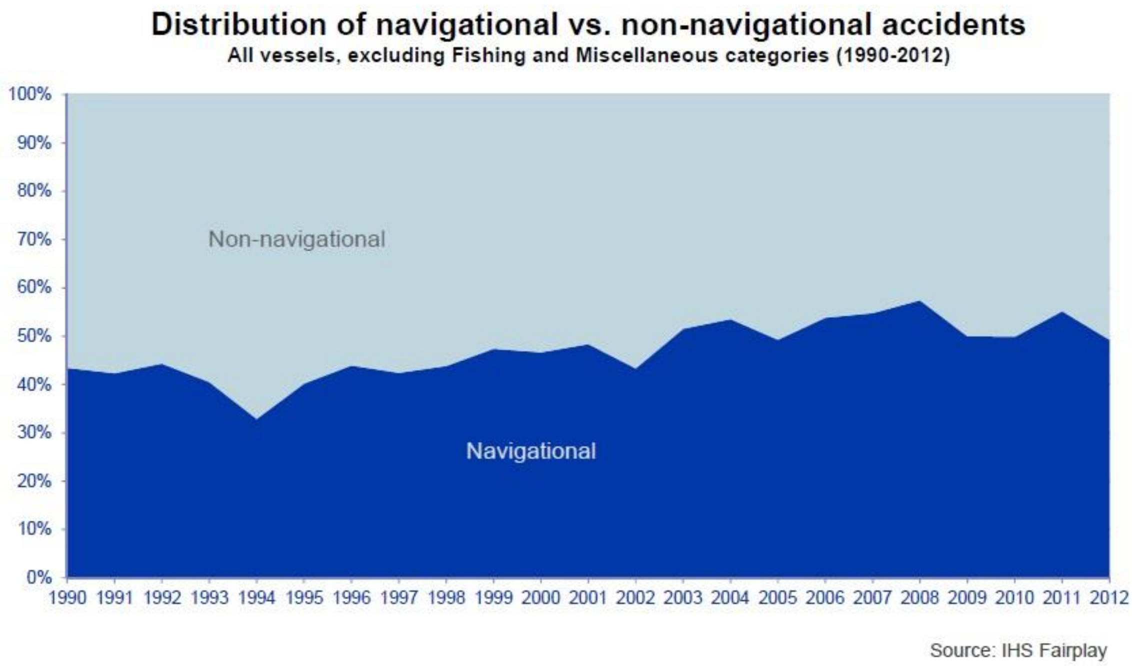

Figure 2.4 Distribution of navigational versus non-navigational accidents

Antão and Soares (2007) conducted a study on HSC accidents compared to conventional ocean-going vessels. From the analysis one could see that the HSC accidents and incidents are mainly related to bridge personnel and bridge operations, where the human element is the key responsible factor in the majority of the accidents. When compared with ocean-going vessels, it is clear that navigational equipment and procedures have a larger preponderance in the occurrence of accidents of HSC. This comparison is shown in Figure 2.5, and make especially note of the first bar which shows navigation incidents (Pedro Antão, 2007).

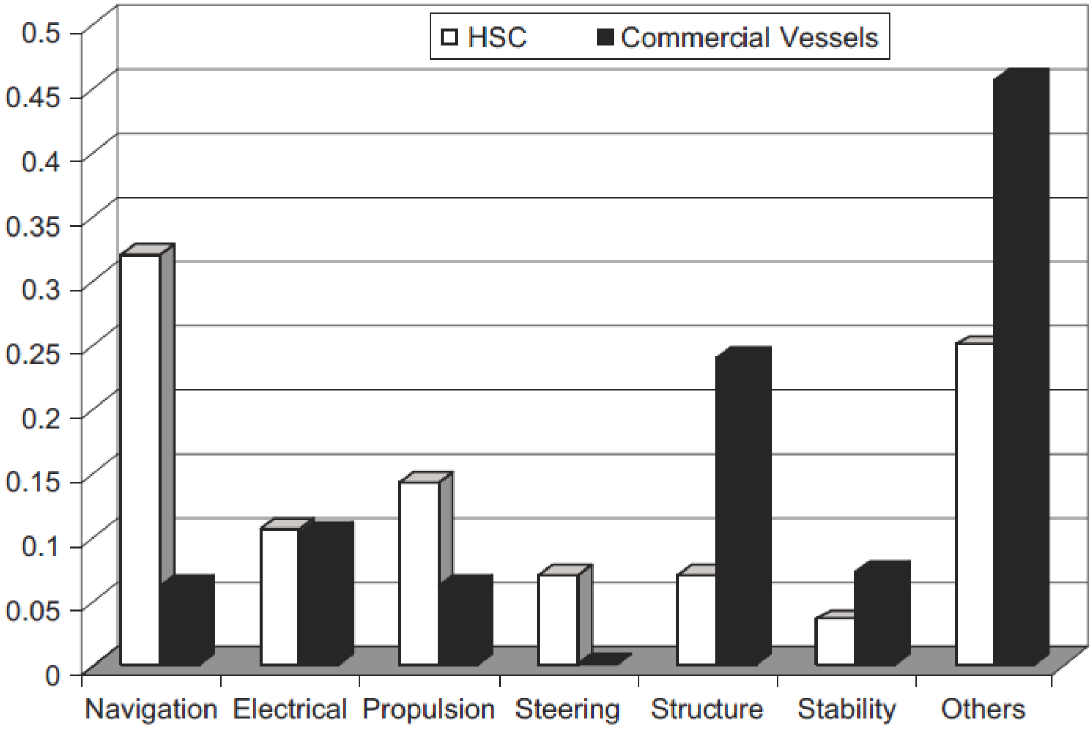

Figure 2.5 Comparison of factors in serious incidents HSC and Commercial vessels.

2.2.2 ECDIS

The ECDIS system can be used to meet IMO/SOLAS chart carriage requirements provided it meets the specified IMO performance standards. The ECDIS must be 'type approved' to ensure it meets these performance standards. An ECDIS that does not comply or follow the relevant performance standards is classed as an Electronic Chart System (ECS)[5] (IMO, 1995).

Some ECDIS systems offer additional databases for tidal information, including predictions and automatic calculation of high water, low water, tidal heights and streams. However, care should be taken when using such information as not all data provided by ECDIS manufacturers is officially authorised or approved by flag states (Standard, 2011).

[5] ECS is not certified as a 'type approved' ECDIS and does not meet or comply with IMO/SOLAS performance standards. The ECS may allow the use of electronic navigational charts (ENC) and raster navigational charts (RNC) with comparable functionality to a 'type approved' ECDIS, but should not be solely relied upon for navigation as the system is not tested nor certified.

Masters and officers should be aware of the limitations of ENC data, including the dangers of overreliance on ECDIS. ENC data can cause operator error particularly as electronic navigational charts contain digitally layered information. Overreliance on ECDIS when using ENC data may prove dangerous if inadequate training and familiarisation has been given (Norris, 2010).

The ECDIS is a complex system that is an aid and navigation tool for the navigator for safe navigation (Kjerstad, 1997b). Its main features are the Electronic Navigation Charts (ENC) and a selection of the inputs given to the ECDIS is amongst others GPS, gyro, echo sounder, speed log, RADAR and AIS. This can vary from ship to ship, but a position sensor input of some kind is needed, and most common is the GPS. ECDIS shows up-to-date information on one screen, has integrated additional services (e.g. AIS, RADAR), enables passage planning and passage monitoring, and enables quick response to emergencies (Norris, 2013a). The complexity of one ECDIS system is shown by the ECDIS system from the manufacture FURUNO in the figure below (FURUNO, 2011).

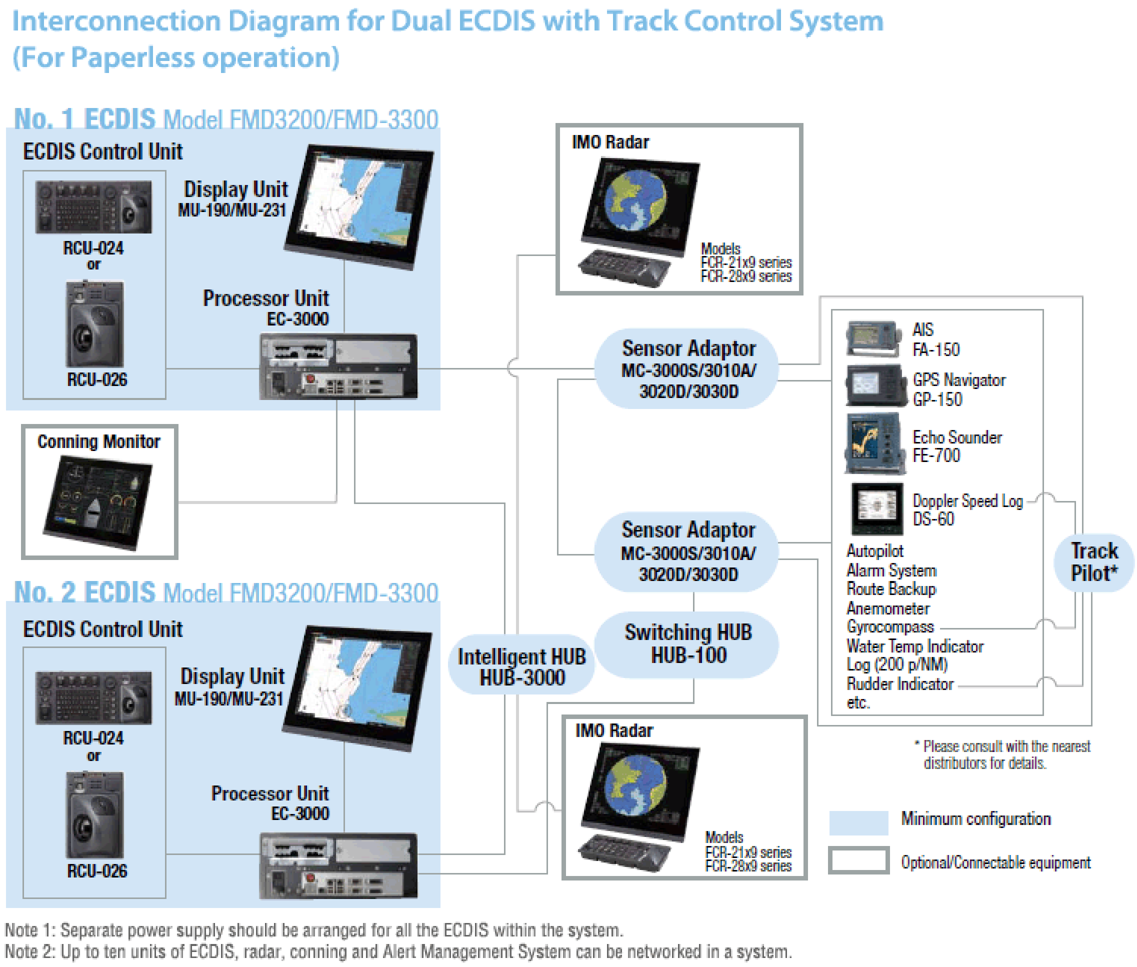

Figure 2.6 ECDIS interface

As seen from the figure, there are several inputs to the ECDIS, and this is just one of many systems. When on board a military ship the systems get more complex and the sensor inputs increase, and an example of a military IBS is shown in Figure 2.7 (Kongsberg, 2008). This implies that the user of the system, the navigator, has extensive system knowledge of the system if something fails.

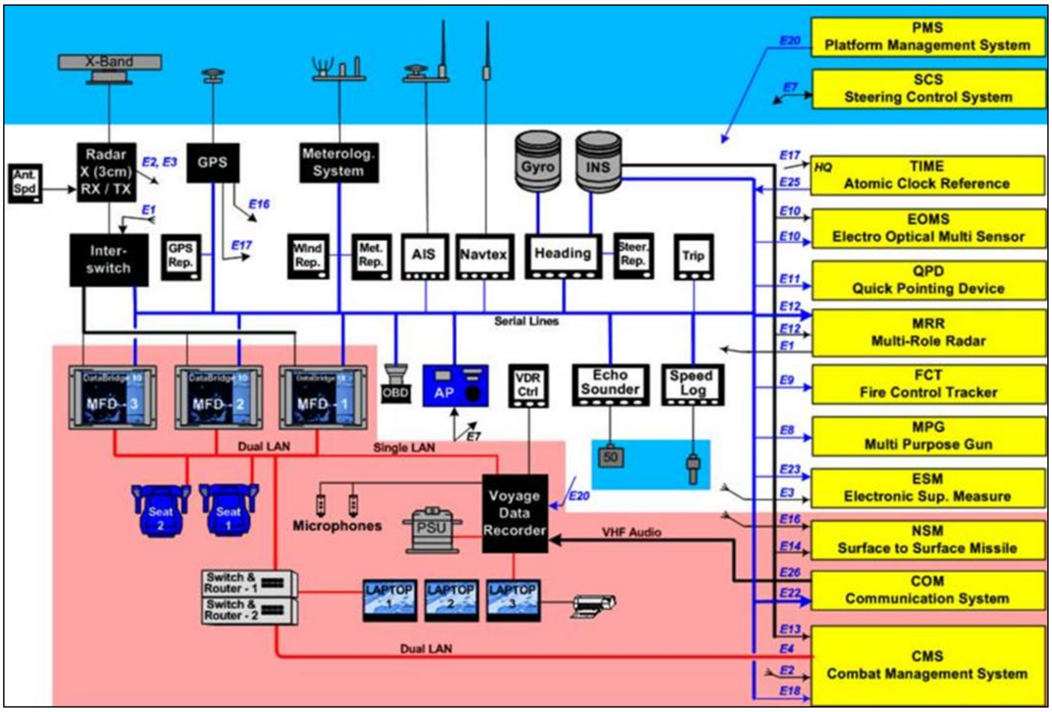

Figure 2.7 IBS of a military ship

When using the ECDIS it is important for the user to know which type of electronic charts and which data quality they contain (Horst Hecht, 2011). The Category of Zone of Confidence in Data (CATZOC) is an essential object attribute to ECDIS, and indicates that the ENC data meets minimum criteria for position and depth accuracy (Norris, 2010). There are six category levels, defined in Table 2.1 (detailed notes omitted) (IHO, 2009).

ZOC Table:

1	2	3	4	5
ZOC	Position Accuracy	Depth Accuracy	Seafloor Coverage	Typical Survey Characteristics
A1	∀ 5 m	a = 0.5 b = 1 Depth (m) / Accuracy (m) 10 / ∀ 0.6 30 / ∀ 0.8 100 / ∀ 1.5 1000 / ∀ 10.5	Full seafloor ensonification or sweep. All significant seafloor features detected and depths measured.	Controlled, systematic high accuracy Survey on WGS 84 datum; using DGPS or a minimum three lines of position (LOP) with multibeam, channel or mechanical sweep system.
A2	∀ 20 m	a = 1.0 b = 2 Depth (m) / Accuracy (m) 10 / ∀ 1.2 30 / ∀ 1.6 100 / ∀ 3.0 1000 / ∀ 21.0	Full seafloor ensonification or sweep. All significant seafloor features detected and depths measured.	Controlled, systematic survey to standard accuracy; using modern survey echosounder with sonar or mechanical sweep.
B	∀ 50 m	a = 1.0 b = 2 Depth (m) / Accuracy (m) 10 / ∀ 1.2 30 / ∀ 1.6 100 / ∀ 3.0 1000 / ∀ 21.0	Full seafloor coverage not achieved; uncharted features, hazardous to surface navigation are not expected but may exist.	Controlled, systematic survey to standard accuracy.
C	∀ 500 m	a = 2.0 b = 5 Depth (m) / Accuracy (m) 10 / ∀ 2.5 30 / ∀ 3.5 100 / ∀ 7.0 1000 / ∀ 52.0	Full seafloor coverage not achieved, depth anomalies may be expected.	Low accuracy survey or data collected on an opportunity basis such as soundings on passage.
D	worse than ZOC C	worse than ZOC C	Full seafloor coverage not achieved, large depth anomalies may be expected.	Poor quality data or data that cannot be quality assessed due to lack of information.

Table 2.1 Category of Zones of Confidence Definitions

With the increased use of technology and integration in different IBS, the demand for system knowledge of the navigator is rising. It has been suggested that the new generation of navigators with higher computer competence than previous generations, will have an advantage when it comes to the use of ECDIS (Smit, 2012). This topic has been studied by Smit (2012) and the finding indicates that those with experience in similar systems had both higher initial and end scores thus indicating relative less perceived learning outcomes. The link between navigational competence and computer competence is shown in Figure 2.8 (Smit, 2012, p. 3)

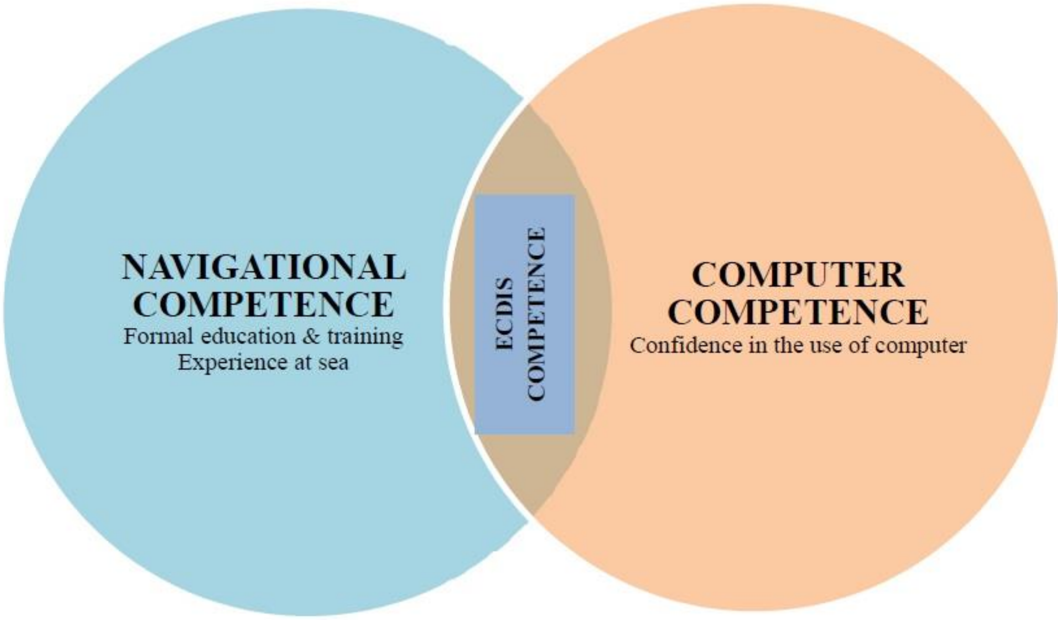

Figure 2.8 Domains of ECDIS competence

Figure 2.8 shows that computer competence as rooted in a more general domain did not transfer to the other, more specific domains, even though some of the competencies were apparently similar. The assumption in the industry itself that the young deck officers have grown up with computers and should be better on ECDIS because of their presumed computer literacy (Norris, 2010), is not supported in this finding. Durso et al. (2006) found that the relationship between experience and performance was not straightforward and there was no evidence for claiming that the quality or even the length of experience necessarily would influence performance positively. Especially when experience in a domain was challenged by a more unusual task, the experienced would not always use his expertise in a profitable way. Similarly when the participants in the ECDIS course used the new tool, they apparently did not make use of former experience in traditional navigation to enhance learning in the use of ECDIS.

With new technology, the problems with technology-assisted accidents occur (Timmons, 2009, Kjerstad, 2008). ECDIS-assisted groundings have become a new challenge that navigators have to be aware of (MAIB, 2008, TNI, 2013). The mandated use of ECDIS springs from the promotion of safety of life at sea. It is a fundamental, though sometimes misunderstood, safety tool that demands real commitment to play its role correctly (IMO, 1995). Skimp on that commitment, fail to provide training and monitoring and the results can be ECDIS-assisted groundings and collisions and a lingering suspicion that ECDIS is another technology foisted on already over-worked navigators and superintendents (UKHO, 2011). When reading the accident reports of ECDIS-assisted groundings (TNI, 2010), a subject immediately becomes clear: where officers are inadequately trained and the equipment is incorrectly set up then things go wrong. In fact, there are comparatively few instances of ECDIS-assisted groundings, but those there are tend to seized on by those who think that every technological step forward is actually a step back. This underlines the importance of system knowledge and familiarisation with the relevant ECDIS system on board (Norris, 2010).

2.2.2 Position sensor inputs

2.2.2.1 GNSS

GNSS has by many been seen as the holy grail for navigation, giving the absolute position at any given time (Spaans, 2000). The most common GNSS solutions of today are GPS, GLONASS, GALILEO and COMPASS/BEIDOU (Hofmann-Wellenhof, 2008). All the different GNSS solutions provide the user with instant position solution of a given accuracy. It is of high importance that the navigator knows the possibilities and limitations in the GNSS which is interconnected to the ECDIS, providing the navigator with an up to date position of the vessel (Spaans, 2000).

Official U.S Government information about the GPS announced that GPS Standard Positioning Service (SPS) Performance Standard will provide a "worst case" pseudorange accuracy of 7.8 meters at a 95% confidence level (MoD, 2008). The accuracy of the GPS signal in space is actually the same for both the civilian GPS service (SPS) and the military GPS Precise Positioning Service (PPS). However, SPS broadcasts on only one frequency, while PPS uses two. This means military users can perform ionospheric correction, a technique that reduces radio degradation caused by the Earth's atmosphere. With less degradation, PPS provides better accuracy than the basic SPS (MoD, 2007).

The precision of the GNSS solution is given by a Dilution of Precision (DOP) value to specify the additional multiplicative effect of navigation satellite geometry on positional measurement precision. To get the position accuracy of a given system, multiply the given accuracy with the DOP value (accuracy of 30 meters with 1,5 DOP value equals 45 metres) (Langley, 1999). There are several different DOP values (HDOP[6], VDOP[7], PDOP[8], GDOP[9] and TDOP[10]) and for mariners who are always at sea level the Horizontal DOP value is crucial. High and low DOP values with regards to satellite constellation are given in Figure 2.9 (Langley, 1999).

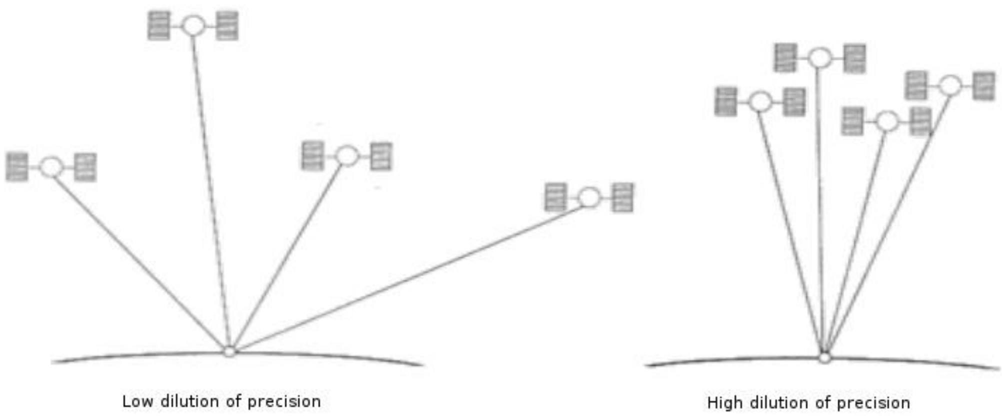

Figure 2.9 Dilution of Precision

Formula used (Langley, 1999):

$$\text{Position accuracy} = \text{HDOP value x Accuracy of service (PPS vs SPS)}$$

The actual accuracy users attain depends on factors outside the system operators control (US MoD), including atmospheric effects and receiver quality (shown in Table 2.2).

There are several error and bias sources in the accuracy of a GNSS solution. The biggest contributor is the ionosphere, but error in satellite coordinates and clock and bias from the troposphere and receiver noise also contribute to the total amount of

6 Horizontal DOP
7 Vertical DOP
8 Positional DOP
9 Geometric DOP
10 Time DOP

error. This is shown in Table 2.1 (Bingley, 2012b). Error is shown in plan and height, and is given in meters.

Error	Full mitigation plan/height	Simple mitigation plan/height
Sat cords (e)	1/2,5	1/2,5
Sat clock offset (e)	1,5/4	1,5/4
Ionosphere (b)	0/0	10/25
Troposphere (b)	0/0	2/5
Receiver noise (b)	0,1/0,25	0,1/0,25
TOTAL	3/7	15/37

Table 2.2 GPS error and biases

Simple mitigation means that the ionosphere and troposphere models are simple and not sufficient to mitigate the bias. Expensive receivers use full mitigation (most marine GPS receivers), while cheap receivers (iPhone) use simple mitigation (Bingley, 2012b).

There is also influence from other sources that the user of a GNSS system needs to be aware of. Multipath is when a satellite signal arrives at the receiver antenna by more than one path, shown in Figure 2.10 (Bingley, 2013). This is caused by reflecting surfaces near the receiver antenna. This is important to be aware of when operating in an area where multipath can occur, such as the Norwegian fjords.

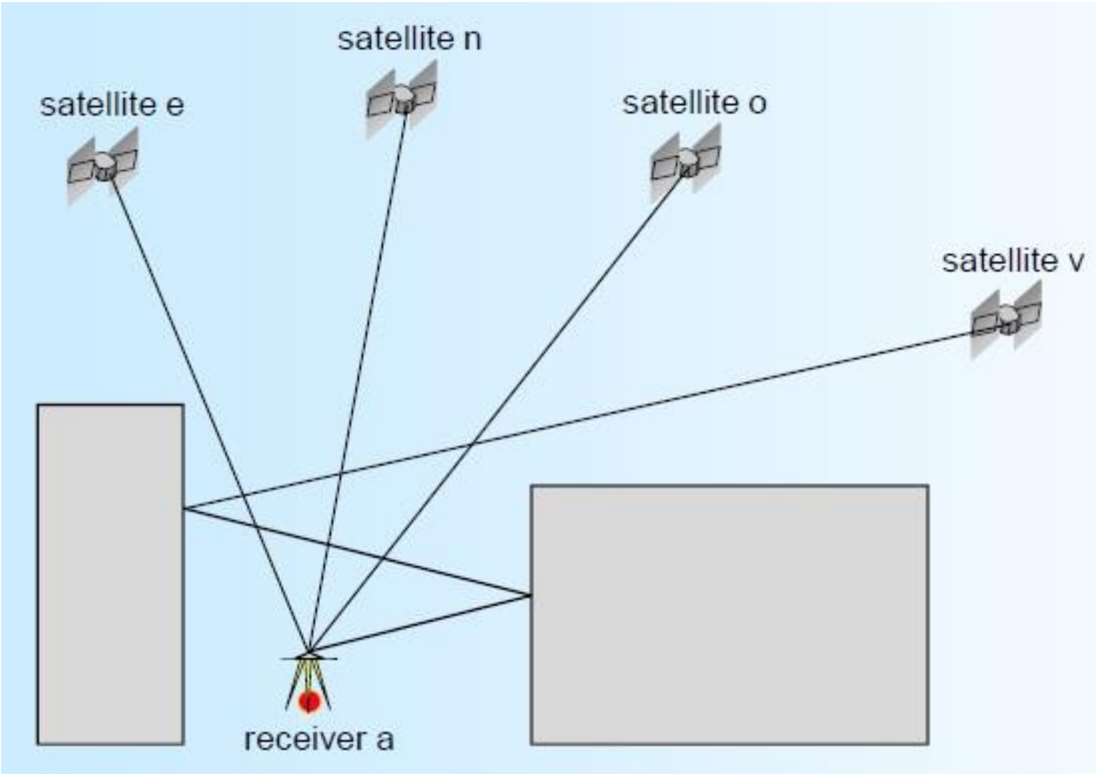

Figure 2.10 Multipath

2.2.2.2 Augmentation systems

For a number of applications, GNSS as sole-means or augmented, has some deviances and its performance does not satisfy the user`s requirements. Space Based Augmentation Systems (SBAS) such as The European Geostationary Navigation Overlay Service (EGNOS) or The Wide Area Augmentation System (WAAS) consist of a space, ground and user segment (Elliott D. Kaplan, 2006, Kjerstad, 1997b). The receiver stations in WAAS and EGNOS form a Wide area Ground-based Network which gives Wide Area DGPS Corrections and Independent Integrity Monitoring (IM). The communication satellites in WAAS and EGNOS provide Broadcast DGPS and IM data to the users and provide additional Ranging source (only with WAAS), via a GPS-like signal within the coverage area. This provides for the users (Norris, 2013a):

1. Improved accuracy
    a. Corrections sent to the user
2. Improved integrity
    a. Independent Integrity Data
    b. Additional ranging
3. Improved availability and continuity
    a. Added ranging source
    b. As a consequence of improved ranging

Figure 2.11 shows the benefits of an SBAS system compared to Ground Based Augmentation Systems (GBAS), such as Ordinary Differential GPS (ODGPS) (V. Ashkenazi, 1993). As shown the error stays the same in SBAS systems when the baseline increases, but be aware that it is within the SBAS coverage area. SBAS is also known as Wide Area Differential GPS (WADGPS). The figure points out the importance of being close to a reference station if using GBAS, and shows the advantages with the SBAS when it comes to accuracy as long as you are within the SBAS coverage area. Plan error is significant for mariners, because the vessel is always at sea level.

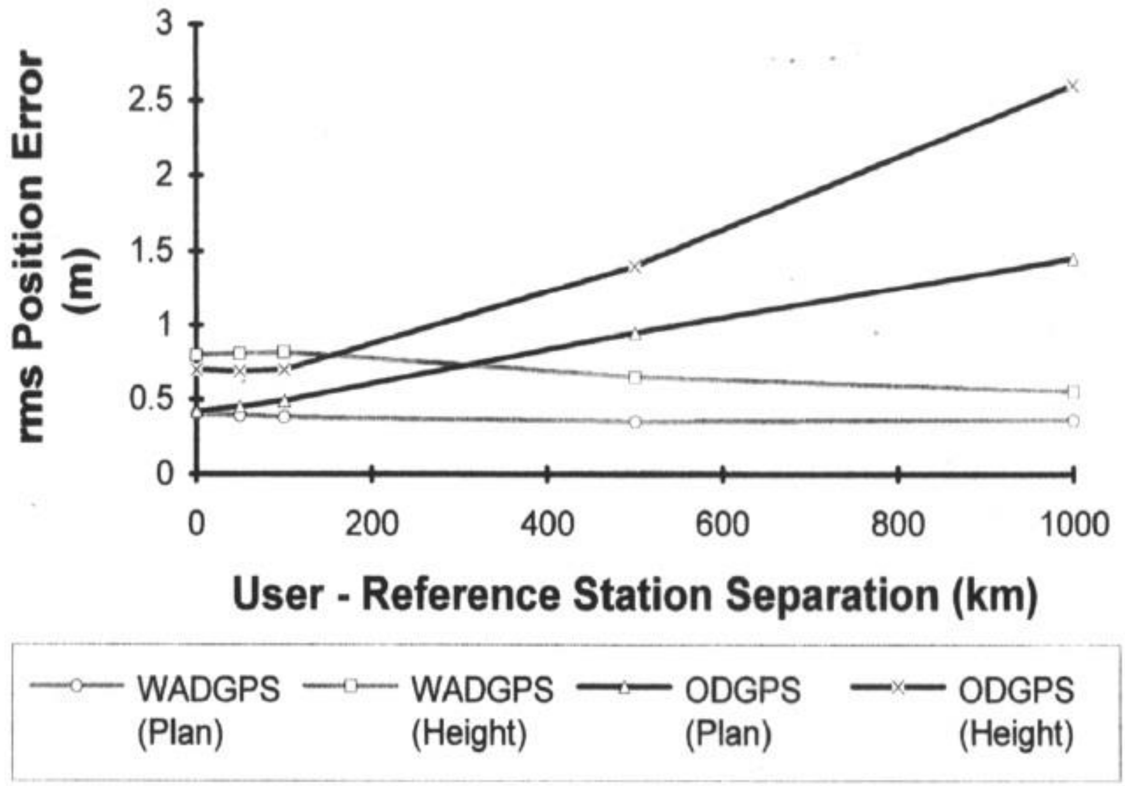

Figure 2.11 Comparison WADGPS and DGPS

The use of GNSS systems in the high-north is vulnerable even when using augmentation systems such as EGNOS or WAAS (Kjerstad, 2006a). Also with global warming and new navigation routes opening, such as the Northwest and Northeast passage, the challenges for GNSS systems are increasing (Kjerstad, 2011).

2.2.2.3 DGPS

Ground Based Augmentation Systems such as DGPS is common in the marine world. The underlying premise of DGPS is that any two receivers that are relatively close together will experience similar atmospheric errors. DGPS requires that a GPS receiver be set up on a precisely known location. This GPS receiver is the base or reference station. The base station receiver calculates its position based on satellite signals and compares this location to the known location. The difference is applied to the GPS data recorded by the second GPS receiver, which is known as the roving receiver. The corrected information can be applied to data from the roving receiver in real time in the field using radio signals (Bingley, 2012a, Kjerstad, 1997b). In the marine world the DGPS is a great resource, and many vessels have the opportunity for such a position input (Moore et al., 2002). The errors and biases to the DGPS are shown in Table 2.2

(Bingley, 2012a), distance in nautical miles (NM) from rover station to user receiver. Error is shown in plan and height, and is given in meters.

Error	10 NM plan/height	270 NM plan/height	520 NM plan/height
Sat coords (e)	0/0	0,05/0,125	0,1/0,25
Sat clock offset (e)	0/0	0/0	0/0
Ionosphere (b)	0/0	1/2,5	2/5
Troposphere (b)	0/0	0,2/0,5	0,4/1
Receiver noise (b)	0,1/0,25	0,1/0,25	0,1/0,25
TOTAL	0,1/0,25	1,35/3,4	2,6/6,5

Table 2.2 DGPS bias and errors

It is important to note that these figures are given to illustrate the amount of errors and biases from each source, and are not to be considered as upper limits (Bingley, 2012a).

2.2.2.3 LORAN

Long Range Navigation (LORAN) is a terrestrial radio navigation system which determines position and speed from low frequency (100 KHz) radio signals transmitted by fixed land based radio beacons. There have been several versions of LORAN, and the latest being LORAN-C and enhanced LORAN (eLORAN) (Kjerstad, 1997b). eLORAN is a LORAN system that incorporates the latest receiver, antenna, and transmission system technology to enable LORAN to serve as a backup and complement to GNSS for navigation and timing. This new technology provides substantially enhanced performance beyond what was possible with LORAN-C, eLORAN`s predecessor. For example, it is now possible to obtain absolute accuracies of 8-20 meters using eLORAN for harbour entrance and approach (ILA, 2010).

The importance of having a back-up system to GNSS is actualize by GPS jamming attacks from North Korea towards South-Korea that have increased in frequency and duration since they began in August 2010. The jamming have prompted the South Korean government to implement an eLORAN system that will cover the entire country by 2016 (GNSS, 2013).

2.2.3 Integrity

The ECDIS will provide an alert if it detects a problem with connected navigational equipment. A concern is that many problems with position will not be automatically detected, especially when using a simple GPS-only positioning system (Norris, 2010). The need for integrity of position on ECDIS can be compared with the need for continuous position control in the paper chart before the introduction of ECDIS. Use of ECDIS simplifies integrity assessment, but the immediacy of own position shown on a computer can give a false sense that integrity checking is unimportant (Norris, 2010).

It is fundamental to make integrity checks on the ECDIS to whatever position sensor input the navigator chooses to use on board the vessel. Over-reliance in ECDIS as a navigation tool without proper integrity monitoring can cause navigational errors. Navigators of today rely too much on what is displayed on the screen, and use the ECDIS in “PlayStation” mode (Norris, 2013a, Kreutzer, 2010, Norris, 2010). Integrity is defined by:

> *Ability of the system to provide the user with data within the specified accuracy in a timely, complete and unambiguous manner. If integrity is compromised, the system should alert the user that all or certain data should be used with caution or not at all (Norris, 2013a).*

Integrity incorporates the following concepts (Norris, 2013a):

1. *Validity*: The conformity of information with formal or logical criteria, or the marking of data as being good or not. E.g. the GPS has too few satellites to give a position solution, and then the data should be marked as invalid.
2. *Plausibility*: Received or derived data should be checked for plausibility. E.g. data from the log speed sensor are showing that the vessel is moving at twice the maximum speed, or if the visual sights give the navigator a different position (visual control). Data are invalid.
3. *Latency*: The time interval between an event and its result. Data should only be combined if the differential latencies are compatible with giving a meaningful result. E.g. the use of data from other ships from the RADAR compared with AIS.
4. *Comparison*: The integrity of information should be compared between (at least) two different sensors. E.g. GPS, Loran-C and visual sights.

Examples of integrity tests can be (Norris, 2013a):

1. GNSS Receiver Autonomous Integrity Monitoring (RAIM) (Hofmann-Wellenhof, 2008).
    a. RAIM detects faults with redundant GPS pseudorange[11] measurements. When more satellites are available than needed to produce a position fix, the extra pseudoranges should all be consistent with the computed position. A pseudorange that differs significantly from the expected value (an outlier) may indicate a fault of the associated satellite or another signal integrity problem (e.g. ionospheric dispersion). Traditional RAIM uses fault detection (FD), however newer GPS receivers incorporate fault detection and exclusion (FDE) which enable them to continue to operate in the presence of a GPS failure.
2. Comparison of positioning sensors.
    a. This is a comparison between primary and secondary positioning sensors, and it will give an alert when the set limit has been exceeded.
    b. Position Deviation Alarms. Comparison of primary and secondary position sensor input, and an alarm will sound if a limit value is exceeded. This value can be adjusted in the setup of the ECDIS.
3. Correlation of ECDIS with RADAR and/or AIS.
    a. Radar overlay on ECDIS or chart contour overlay on RADAR from ECDIS.
    b. Use of parallel indexes on the RADAR set.
4. Measured depth (from echo sounder) with chartered depth (used by submarines).
5. Correlation of radar overlay with conspicuous targets.
6. Integrity check by visual sights (e.g. 3 lines of position and other means of visual sights).

2.2.4 Control of ECDIS

Control of the position sensor input to the ECDIS can be done by several methods, but the use of visual sights and the use of conventional methods such as radar for positioning are the most common. The use of visual sights such as cross bearing, 4-bearing, ½-bearing and aft heading point is discussed in a previous master thesis

[11] The pseudorange is a measure of the range, or distance between the GPS receiver and the GPS satellite. Since there is accuracy errors in the time measured, the term pseudorange are used rather than ranges for such distance.

written at the University of Nottingham (Bøhn, 2011), and a short description of these methods is given in Appendix G. There is also literature used at the Royal Norwegian Naval Academy that lay these principles out (Oi, 1993, Kjerstad, 1997a), and it can also be found in English publications (National Research Council, 1994). It is important for the reader to understand that these matters of visual sights are something that every military navigator has in his backbones, and it is applied both on paper and digital charts. Civilian navigators do not use visual control methods to the same extent, but it is covered in the syllabus of a navigation degree (UiT, 2013). On ECDIS, you have the opportunity of taking several position lines (Norris, 2010), similar to cross bearings. All other methods of position fixes are also possible on the ECDIS, but the layout and interface are different from manufacturer to manufacturer.

With more and more technology being added to the working environment for the navigator, there are several conventional methods of control with technological aids which can help the mariner in controlling the ECDIS. Interface with RADAR and AIS are two essential aids. With the use of overlay from RADAR, or even overlay from ECDIS to the RADAR, the mariner can compare the position sensor input (e.g. GNSS) with the picture from the RADAR (Norris, 2008). This is shown in the figure below where chart contour is used on the RADAR.

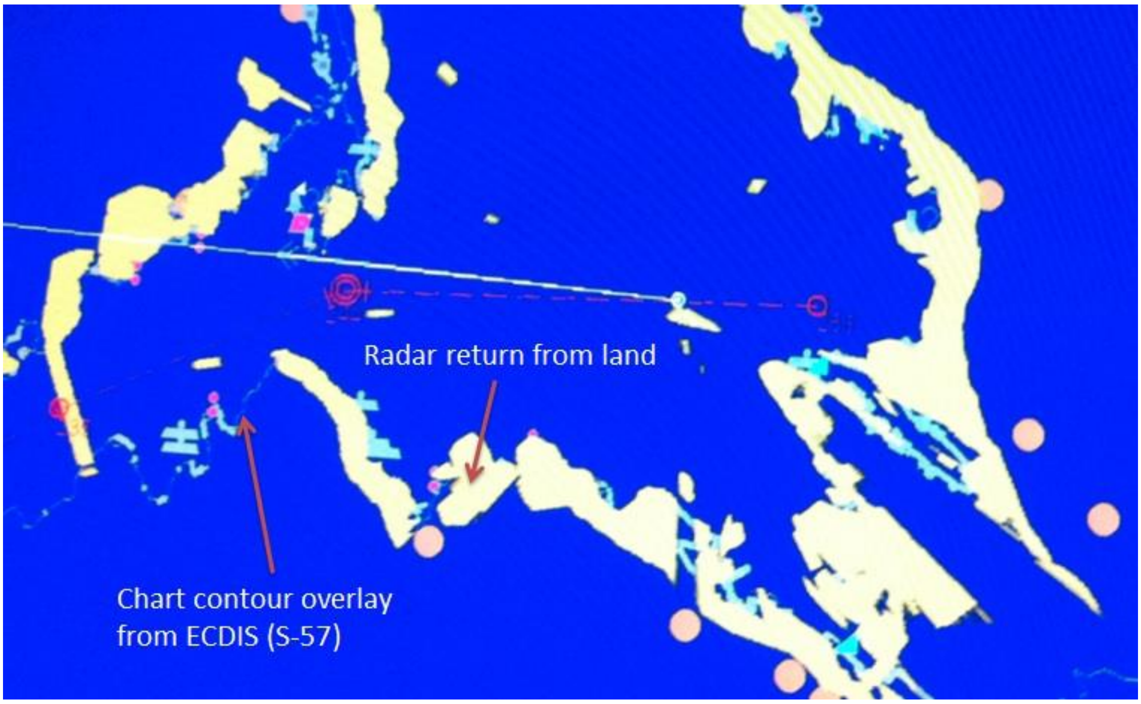

Figure 2.12 Chart contour overlay on RADAR

2.2.5 RADAR

It is essential to be aware of the possibilities and limitations in the RADAR set when using it to control the ECDIS (Norris, 2013b). There are several manufacturers within the RADAR industry, and the parameters are different from set to set. It is decisive to use a conspicuous target, and be aware of which directions the RADAR has the best functionality. Land and targets in front of the vessel will be strained and will seem bigger than they are. Land and targets abeam and closer to the vessel will be presented more exact (Skolnik, 2001). It is important that the navigators assess each target or land details that are used for the control of RADAR, and that the navigator is aware of the possibilities and limitations of his/her RADAR set. HSC have a RADAR set operating in the 9 GHz band (X-band) (IMO, 2002). RADAR theory is outside the scope of this thesis, but a recommended book is *Introduction to Radar Systems* by M. I. Skolnik (2001) or *Basic Radar Theory* written by KNM Tordenskjold (2002). Fundamental parameters for the navigator to be aware of are: Frequency, horizontal beam width, pulse repetition frequency (PRF), rotation per minutes (RPM), pulse length (short, medium and long) and it is essential that the navigator knows how to tune the given RADAR set to the given weather conditions (tune, gain, anti-clutter sea, anti-clutter rain). Note that a RADAR set needs constant tuning with changing weather conditions, and is not supposed to be set on a “standard” setting.

2.2.6 AIS

Automatic Identification System is a maritime navigation safety communications system standardized by the International Telecommunication Union (ITU) and adopted by the International Maritime Organization (IMO) that provides vessel information, including the vessel's identity, type, position, course, speed, navigational status and other safety-related information automatically to appropriately equipped shore stations, and other ships within VHF-range. It is a VHF based system on two channels, typically 87B and 88B (162 MHz). In short terms AIS is an automatic radio communication system where all ships broadcast information about themselves on two different VHF frequencies (IMO, 2001, IMO, 1998).

The data transmitted is divided into three subgroups (Norris, 2008, IMO, 1998):

1. Static data

   a. IMO number, Ships name, Call sign, Type of Vessel and location of position-fixing antenna on the ship.
2. Voyage related data
   a. Destination, Estimated Time of Arrival (ETA), ships draught, cargo and route plan (optional) is transmitted every 6th minute.
3. Dynamic data.
   a. Position, time in UTC[12], heading, course, speed, navigational status, rate of turn, pitch and roll (optional) and angle of heel (optional) is transmitted every 2 seconds to 3 minutes dependent on the vessels current speed. That means that a high speed vessel transmits its data every other second and a ship at anchor transmits its data every 3rd minute.

Control of the position sensor input to ECDIS can also be controlled by comparing the echoes from a vessel on the radar with the AIS track, which gives a good indication on deviation in the position sensor input (either on the ECDIS or the AIS). This is shown in Figure 2.13 and Figure 4.9 (page 74).

[12] Coordinated Universal Time (UTC; French: Temps Universel Coordonné) is the primary time standard by which the world regulates clocks and time. It is one of several closely related successors to Greenwich Mean Time (GMT). For most purposes, UTC is synonymous with GMT, but GMT is no longer precisely defined by the scientific community.

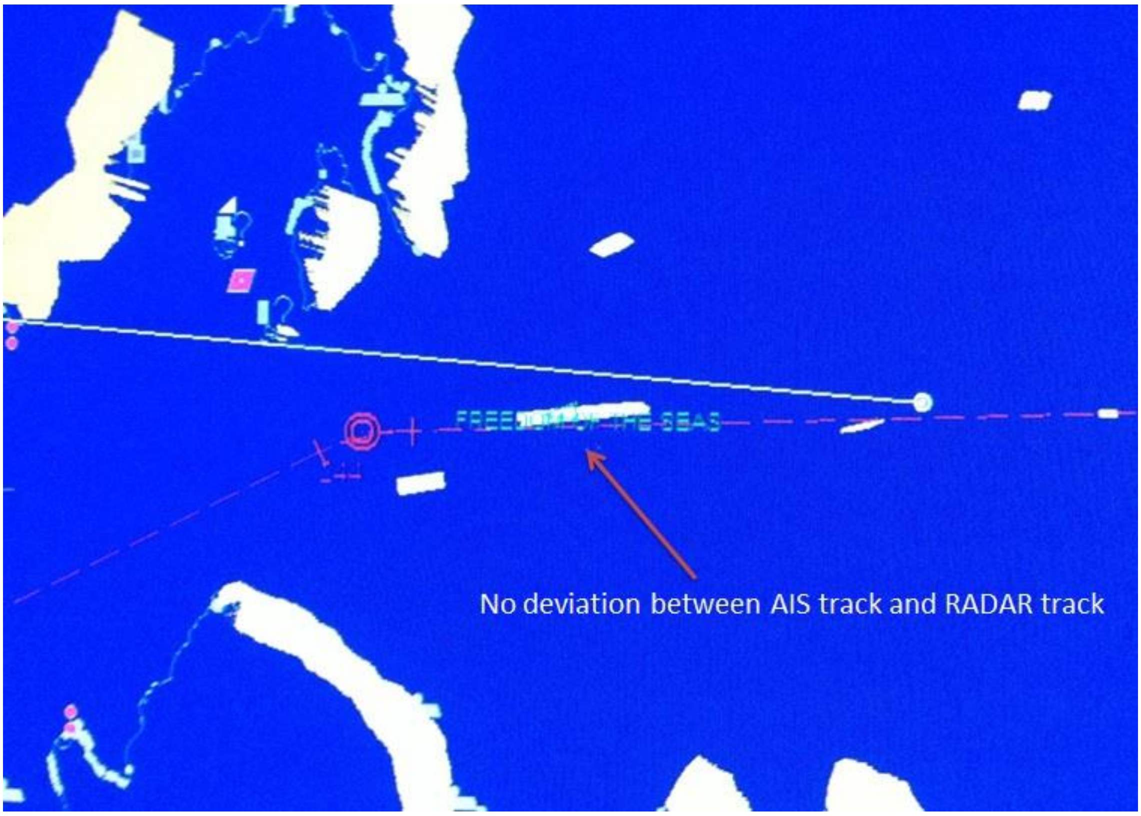

Figure 2.13 Comparison of RADAR track and AIS track.

When controlling the ECDIS, AIS can be used as an indication whether or not the GPS is working properly. If there is a deviation between the RADAR track and the AIS track, this is an indication of deviation on the system and should be looked into. It might also be a technical error in the AIS, and AIS is also easy to spoof. Most AIS have a built-in GPS, and an error in the built-in GPS in the AIS can arise. This error in the built-in GPS in the AIS can accrue independent of an error in the primary GPS sensor of the vessel (Norris, 2008).

When using the AIS integration on the ECDIS and the RADAR, it is crucial to be aware of the AIS fusion function (Norris, 2008). This fusion is to be used to provide the navigator with less information, and therefore the track from the RADAR and the AIS is fused into one track which is presented. If there is a deviation in the system, the fusion function can prevent the OOW of seeing this as the two targets from the RADAR and the AIS are fused within a given distance limit. This limit can be adjusted on the different sets, and it is important that the OOW knows which limits are used if the AIS is to be used to detect deviation in the position sensor. The OOW should assess if the fusion functions should be turned off if he/she suspect deviation and want to control the ECDIS by comparing AIS and RADAR track data.

2.2.7 Familiarisation

The introduction of ECDIS also demands new training for navigators. IMO Model Course 1.27 "*Operational use of Electronic Chart Display and Information Systems (ECDIS)*" is covering this aspect (IMO, 2012), and consist of two main parts: Generic ECDIS training and familiarisation. This course has been revised by IMO several time, and the latest version being from 2012. During the past years, there have been several studies on what this course should comprehend. System knowledge, simulator training in the use of the system and familiarisation of the specific system which is used on board are main findings and topics which are stressed (Kjerstad, 2006b).

There are many different manufacturers of ECDIS solutions, and there are just as many different ways of interface and set-up on the ECDIS which the mariner must know how to use. This is why *familiarisation* is very important for a navigator on board the ship using the systems which the navigator will use in his/her day-to-day work (Gale, 2009). One of the problems with many different manufacturers of ECDIS is that the layout and interface is slightly different from one producer to another. This is confusing for a navigator when changing vessels, and he/she has to cope with a new system with slightly different interface on its ECDIS. Familiarisation of the equipment which the navigator is to use is therefore fundamental (Norris, 2010). Users that are new to an ECDIS-installed ship must confirm they have sufficient knowledge of the system on board. Such check lists can be found in Norris (2010) page 193-198 and is a good guidance for the navigator when it comes to the familiarisation of the vessel specific ECDIS. Compared to aviation, which only has two major manufacturers (Boeing and Airbus), the use of check-list and the importance of familiarisation have been neglected (Bonner, 2013).

2.2.8 Human Machine Interface

Robbins (2007), Gould (2009), Knappen-Roeed (2008) and Dobbins (2004) have looked at Human Machine Interface in general and in HSC in specific. Results from studies have shown that the introduction of ECDIS improves the course-keeping performance, and significantly reduces the total amount of communication on the bridge. It is also an interesting finding that thus the ECDIS reduces communication on the bridge, there is no evidence of ECDIS relieving the navigator of any workload (Gould et al., 2008). There are also studies of Performance-Shaping factors (PSF) associated with navigation accidents in the Royal Norwegian Navy revealing that demand-capability balance[13] and work organization and distribution[14] are the main factors for navigation accidents, statistics shown in Figure 2.14 (Gould et al., 2006).

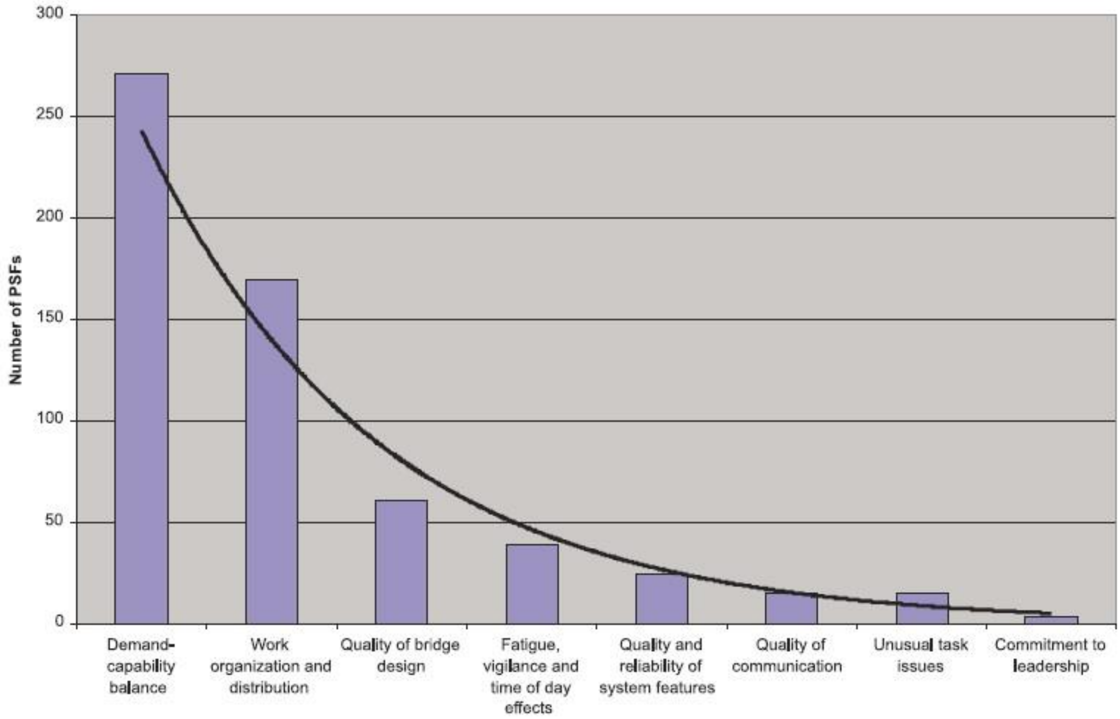

Figure 2.14 Performance-Shaping Factors in navigation accidents

It is shown that in high speed, the mental capacity of the navigator and his or her workload coincides with the errors the navigator makes. It is therefore essential with further development of all the factors that can relieve the navigator from workload and make the navigation environment safer, more efficient and intuitive. ECDIS is one of several means to this aim (Gould, 2009).

[13] Required time for completion, time available for operator performance, time pressure (time required vs. time available), knowledge level, attention, perceptual requirements, required level of cognition, operator expectations, anticipatory requirement, experience level, work methods, amount of required information, task criticality, requirement on and type of feedback, suddenness of onset, level of training, necessity of auxiliary tools, routine violations.

[14] Adequacy of distributed workload, intra/interteam cooperation, operator diagnosis, operator skill level, ability/leadership/authority of team leader, perceived importance, number of simultaneous goals/tasks, overlap with previous tasks, calculational requirement, clearness in job/role definition, clearness in responsibilities/communication lines, team cooperation requirement, communication requirement, clarity of instruction and terminology, procedure quality, concurrent activities and interruptions, degree of reference to other materials than procedures, shift rotation.

Studies show (Dobbins, 2004) that due to many different manufacturers, HMI and Interface with essential navigation equipment is poor. An example is the optical bearing device (OBD) which some vessels have and use to take several lines of position to conduct a cross fix. In an environment with high speed which is rapidly moving with constant vibration, it is fundamental that the OBD is well designed for functional use by the navigator (Røed, 2007). Also the use of Arm Rest Panels (ARPs) is used on the Skjold-Class, and this is proven to be efficient for easy access to the most used buttons and to conduct adjustment with settings on equipment in the INS (MAPPS, 2005).

Chapter 2.2.9 and 2.2.10 is written for the reader to better understand chapter 4.1.1 and 4.1.2 Findings.

2.2.9 Skjold-Class FPB

Information regarding size, technical description, capabilities and operational pattern is referred to Appendix A.

The bridge of the Skjold-class is set up to accommodate two navigators at any time. On the port side is the seat of the OOW, on the starboard side is the navigator seat. The navigator conducts all navigation, and the OOW has the opportunity to overrule the decision of the navigator by VETO. There are specific procedures with regard to how the navigation team is working, and also procedures for all communication in the navigation team. This is laid down in the Norwegian Corvette Training Centre (MTBTS) Bridge Manual (Norwegian: Bromanual) (MTBTS, 2009). The sensors which are used is also described in a Standard Navigation Procedure (SNP) which is common to RNoN published by NNC (2012), and the Skjold-class IBS is shown in Figure 2.7. Studies emphasize the importance of thorough and well-known procedures and manuals in use on board (Gould et al., 2008).

The normal education for a navigator on a Skjold-Class FPB at the Norwegian Corvette Service (MTBV) is several courses after finishing RNoNA and a bachelor degree in navigation. First out is an introduction course which is part of the final semester at the RNoNA and has a duration for one week. This is called “6th Semester Navigation Course” (6NK), which aim is to learn the navigator how to conduct route planning and use the INS in general and ECDIS (Kongsberg SM-10) in specific on board. The next course digs deeper into the system knowledge and use of the navigation systems, and is called “Skjold Navigation Course” (SNK). SNK consists of one week of sailing and one week of education in the class room. The final course before becoming an independent officer of the watch is the “Skjold Officer of the Watch Course” (SVK). SVK consists of two weeks combined class room education with simulator training, and one week on-the-job training and evaluation on board. All curriculums are written and made by MTBTS. Due to their confidentiality they are not referenced to in this work. 6NK and SNK are informative courses, while SVK is used as a benchmark and candidates can fail this course. 6NK and SNK are conducted within the first year at MTBV. SNK is normally conducted when 2-3 years of experience is gained, but recommendation is needed both from the captain and a board for each individual candidate to enter SVK. The consequence of not passing is that the candidate cannot conduct an independent watch as OOW. If a candidate fails several times, he/she will be recommended alternative duty with other types of Navy vessels. This is due to the fact that *not everyone can handle the high amount of workload and pressure it is to conduct safe navigation with a military HSC* (statement from interview with staff MTBTS). The education set up for a navigator on a Skjold-Class is shown in Figure 2.15.

Figure 2.15 Education for navigator at Skjold-Class FPB

Each navigation team of the Skjold-Class must perform a navigation muster in a 1:1 simulator to become a verified team in navigation. This verification is done by MTBTS. The aim is laid down in the Periodical Operational Evaluation (OPUS) (MTBTS, 2011), and amongst other subjects, methods of control of ECDIS are tested.

2.2.10 Civilian HSC

Informal interviews with the crew on board gave the following information about NorLeds conduct of operation: The HSC of NorLed are carrying passengers from different towns and villages along the Norwegian coast. The operational pattern is known for many arrivals and departures, and a constant pressure to keep a tight time schedule. Depending on the size, there will be one or two navigators on board. If the HSC exceeds 25 meters there are two navigators on board according to Norwegian law (MFA, 1994). When they are two navigators one of the navigators also has to sell tickets to passengers or help out with work on deck, so there are seldom two navigators on the bridge at any time.

NorLed did not want to distribute their procedures, so these are not known.

The navigators on NorLeds HSC have to conduct an HSC course, e.g. at Aalesund University College (HiAls, 2012), which is regulated by the Norwegian Maritime Directorate (NMD, 2012, $65). The focus of this HSC course is HSC regulations, leadership and Crew Resource Management (CRM). It does not have a practical or theoretical part of how to conduct high-speed navigation. There have been studies with regard to what is expected by an HSC navigator (Kjerstad, 2003), and it is clear that the demanding and harsh environment makes this a challenging job as a navigator. It is therefore important that the navigator has relevant training, and simulator training is more and more in use[15]. In the last couple of years there have been several navigation accidents with HSC in Northern Norway, emphasizing the importance of education and experience in the challenging job as a navigator of an HSC. The problem of making a good and relevant HSC course has not been solved, and some of the frustration can be shown in a statement from the former CEO of the Norwegian Maritime Directorate: "*It is not forbidden to run aground…the navigators have not broken any rules or legislation. This means the ship-owner needs to act, send them on a course or something…"* (NRK, 2010).

In this literature review the regulations for ECDIS are given, and it is further discussed how ECDIS can be used as an asset for every navigator's desired end-state: Safe Navigation. National and international statistics show that there has been a slight increase in navigation accidents during the implementation time of ECDIS, but the conclusion of this reason is not clear. The statistics can only be seen as a trend, and it needs further investigation to say what exactly the ECDIS has done to enhance safe navigation. Global Navigation Satellite System with its augmentation systems such as SBAS and GBAS is described, and its errors and biases briefly described. Visual and conventional control methods for integrity checks of the position sensor input to ECDIS

[15] HSC course at Aalesund University College uses simulators in their training: http://www.hials.no/eng/content/view/full/40796/language/eng-GB

are described, and the importance of continuously controlling the position sensor input to ECDIS accentuated. Studies show that ECDIS has developed the work environment for the navigator, but it has not taken workload off the navigator. Further it is shown that the trust in GNSS as a position sensor for ECDIS is very high due to its high reliability, but navigators need to be aware that they tend to over-rely on ECDIS without proper integrity monitoring. The literature review has not delved into the facts on GNSS and its augmentation systems, but the main point is for the reader to be aware of the fact that the system can fail. A short description of the difference between military (Skjold-class) and civilian HSC navigation is given. There are several means of integrity monitoring, and in the proceedings of this paper the main focus will be on control methods of the position sensor input to the ECDIS.

3.0 Research methods

In the literature review there are several examples of how ECDIS should be used in conjunction with its relevant sensors in an IBS, and how system knowledge is crucial for navigators of today to understand the possibilities and limitations within the system in use. Integrity checks of the ECDIS are of utter importance to enhance safe navigation. From the literature review it is shown how this was done with paper charts before the introduction of ECDIS, but with the paradigm shift from paper chart to electronic charts, there is not much research on which control methods used on the ECDIS are most efficient. It is important to integrate the knowledge from earlier days, with visual control of the passage, with today's conventional methods of control for the OOW on the bridge of any vessel.

In this thesis the research methods, in addition to the literature review, comprehend a field work which is divided into three subsections:

1. Practical field study on board military and civilian HSC.
    a. One week was spent on board HNoMS Gnist, which is one of the world's fastest and most advanced Fast Patrol Boats (Janes, 2013). Aim is to observe how navigation teams conduct safe navigation with regards to research objectives 1 and 2.
    b. Three days was spent on board different HSC carrying passengers from the company NorLed. Aim is to observe how navigation teams conduct safe navigation with regards to research objectives 1 and 2.
2. Simulator tests conducted to examine when navigation teams detect an offset in the GNSS. The simulator test was conducted at the Royal Norwegian Navy Navigation Centre, which has a state-of-the-art simulator department. In compliance with research objective 3.
3. Interviews and questionnaire with navigators conducted to examine the use of visual and conventional control methods and system knowledge, with regards to research objective 4.

3.1 Limitations

Control of the position sensor input to the ECDIS has been defined and are split into two:

1. Visual control, with visual sights such as the traditional cross fix with several lines of position.
2. Conventional control by the means of controlling and comparing two (or more) systems (Integrity check, comparison). An example of this is radar overlay (correlation of radar return on conspicuous objects with charted position).

Only vessels of the type HSC (Kjerstad, 2003, IMO, 2008) are used in this thesis, with a tonnage below 3000 GT due to IMO regulations.

3.2 Field work

In the period of 5 June 2013 to 18 June 2013 data were collected from observations on board three different HSC, in simulator tests and with qualitative means in the form of interview of navigators. Field work report is given in Appendix B.

3.2.1 Field study on board HSC

During the field study on board civilian and military HSC, area of sailing will be all along the Norwegian coast. This is a demanding environment with many islands, skerries and underwater rocks. The military HSC will operate between Andenes in the north of Norway and Trondheim in the middle of Norway. Civilian HSC traffic between cities and densely populated areas on the western coast of Norway. Areas are shown in Figure 4.1, 4.2, 4.5, and 4.6.

The reason for joining different HSC navigating along the coastline of Norway, was to collect empirical data of which method of control are commonly used on board to control the position displayed in the ECDIS (research objective 1 and 2). By collecting data from several sources the database will be broader. It is also important to collect data from both civil and military HSC, to explore contingent divergence in the methods of control. When observing a team for a longer period of time (one week), there will be a greater chance of collecting all data used by the navigation team. This especially compared to simulator tests where the navigation teams are put into a controlled environment, and thus the behaviour pattern of the team can change compared to their normal and familiar surroundings on board the vessel.

3.2.2 Simulator tests

A simulator test was conducted at the NNC which has a well-equipped simulator department. NNC is the centre of excellence in the field of navigation in the RNoN. Its simulator department consists of five mid-sized and one full-size simulator. This is further explained in Appendix D.

The simulator test comprised five navigation teams, all sailing the same area on the same route. Area of sailing is given in Figure 3.1. The route was decided and planned by the author, using the Notation of the Norwegian Navy (NNC, 2007) which details can be found in Appendix E. This notation and the routes are familiar to all the navigation teams, and they received the routes one week prior to the tests to ensure that the route was well-known. This was done to have the exact same scenario for all five navigation teams.

The scenario consisted of a one hour long voyage (length of voyage dependent of Speed of Approach (SOA) of the vessel type), in littoral waters between Bergen and Sognefjorden along the west-coast of Norway. The sailing route is shown in Figure 3.1.

Figure 3.1 Sailing route simulator test

The navigation teams were told to conduct a normal watch, and they were to conduct efficient navigation[16] between Bergen and Sognefjorden. The teams were given time to set up the systems on the bridge in accordance with the setup on board, making the HMI familiar. Groups number 3 and 5 from the Skjold-Class sailed in a 1:1 simulator, which is exactly the same as on board. Groups 1, 2 and 4 did not use a 1:1 simulator, but the systems` interface are the same as the navigation teams have on board.

The aim of the test was to explore when the navigation teams detected a fault in the position sensor input, and how the navigation teams addressed the fault (research objective 3). The test was conducted with all systems operational for 30 minutes of

[16] NNC definition, see 2.1.1 *Definitions*.

sailing without any error on the primary position sensor input to the ECDIS (GPS), and then gradually starting to drift the position with 10 meters per 10 second in north and east direction for the final 30 minutes of the test.

3.2.3 Interviews

20 interviews were conducted with navigators during the field work period. The aim of these interviews was to explore what control methods the navigation teams used, and explore their system knowledge (research objective 4). This was divided into two subsections, where part one consisted of questions regarding control of position sensor input to the ECDIS. Part two consisted of system knowledge and was conducted in co-operation with fellow student Steinar Nyhamn (2013). The interview guide can be found in Appendix C. The interviews were all conducted on board the vessel.

3.2.4 Validity and reliability

Validity refers to how well a test measures what it is purported to measure (Johannessen et al., 2004). Validity is substantiated by attending both civilian and military HSC, and this is done to uncover any divergence between civilian and military way of navigation. Collecting data live with field studies on board military and civilian HSC, and then testing the specific control methods in a simulator both enhances validity. With this in mind, the representation of the real world and how navigators control the ECDIS should be represented. It is important to acknowledge the fact that when an observer joins in on the bridge of an HSC, the navigation team might change their behaviour. With one week on board, sailing with several navigation teams, the normal behaviour of the navigation crew is presumed uncovered. As mentioned, there is always a possibility that the navigation team will conduct the navigation differently when observed or in a controlled environment as in a simulator, and this is something that needs awareness.

Validity was also controlled by conducting workshops and meetings with scholars at AUC, Vestfold University College (VUC) and RNoN in the beginning of August 2013. During this workshop a presentation was given on this research project, and findings were discussed. The feedback from this workshop has been implemented into the thesis, and enhances the validity in the thesis. Presentation is given in Appendix F.

Reliability is the degree to which an assessment tool produces stable and consistent results (Johannessen et al., 2004). During the fieldwork several navigation teams will be monitored, which gives the opportunity to get an average of how a navigator conducts the control of ECDIS on a normal watch. In simulator tests all the environmental affections are controlled and similar to all navigation teams, and this will produce a more stable and consistent result which can be easier to compare than the data collected on board the HSC. The reason for this is the constant changing weather and surroundings which the HSC are operating in, and there will also be other matters from the constant changing environment which will affect the navigation team that are constrained in the simulator tests (Yin, 2003). Due to a relative low number (five) of participant navigation teams in the simulator, you could argue that the total number of teams is too low to have a significant value and conclusions to be made. Even though only five teams participate, it will show a trend and give valuable data for analysing. Since the aim of the test is very specific (only one aim), it can be easier to see a trend with few participants. For better reliability a higher number and more civilian navigation teams should have conducted the simulator tests. This was unfortunately not possible during the period where the simulator tests took place.

Reliability has also been enhanced by conducting a sea trial in the middle of August after the data from the field study was collected and findings evaluated. During this sea trial all the methods of control of the position sensor input were tested. The sea trial was conducted with a Rigid Inflatable Boat (RIB) with ECS system, sailing out from RNoN and southwards towards Leirvik, same route as shown in Figure 4.4. All visual and conventional methods of control were tested during this sea trial, and the advantages and limitations were controlled towards Table 4.5.

Both formal and informal interviews have been conducted (Gummesson, 2000). The formal interviews were conducted with an interview guide and on a one to one basis, the interview guide is given in Appendix C. Informal interviews were conducted throughout the field work period, to gather as much information as possible from the thoughts and opinions of the navigators and scholars (research objective 4).

It is of high importance for the researcher to know that when entering a working environment as the bridge of a ship as an observer, the team might change its behaviour (Alvesson, 2001). If possible more time should be spent with the teams so that they work and respond as if the observer does not take part of the exercise. The navigation teams will be informed about the presence of the observer, but will not be given a specific reason for the observer`s presence. This is done to assure that the navigation team does not change its behaviour in this specific field which the observer is supposed to gather data from.

When doing live observations both in field work on board civilian and military HSC and in simulator tests, it is essential that the observer is aware of his or her own perception of the observations (Thagaard, 2003). The observer might affect the current situation which he or she is observing, or the observer might misunderstand the current observation. The author has been a navigator at the Skjold-Class, and might be affected by this experience. It is thus important to be aware of this, and when doing observations try to be as objective and open for new observations as possible (Thagaard, 2003). This is also of high importance when conducting interviews, so that the opinions of the author do not affect the opinions of the interview objects (Ryen, 2002).

In the simulator tests structured observations were the aim of the test. According to Johannessen et al, (2004) observations can be divided in structured and unstructured observations. The simulator test scenario was made as simple as possible, and only one observation was of the main interest. In a complex scenario it is not always easy to foresee what is going to happen when underway. Consequently, it turned out to be a combination of structured and unstructured data. Due to this fact it is important to sum up all the observations within a short time after the tests (Johannessen et al., 2004, p. 133). The findings were organised and summed up within 9 days.

The research method of this thesis comprises of three subsections: A practical field study on board military and civilian HSC, simulator tests and interviews and questionnaires. This is done to enhance validity and reliability of the research project aim which is to improve and develop the methods of control of position sensor input chosen to ECDIS.

4.0 Findings

The overall aim of the research project is how to improve and develop the control of position sensor input chosen to ECDIS on a High Speed Craft in littoral waters. In the literature review it is referred to literature addressing this matter. It is laid down how ECDIS works with integration to different position sensors with their advantages and limitations. It is also shown with statistics and through literature that even though ECDIS has revolutionized navigation, it is important to conduct control of position sensor input the same way as was done with the paper charts to avoid serious accidents. With new technology there are also new challenges with regards to HMI and different stress factors that the user needs to be aware of to utilize the system to its full extent. Further on it is explained how the research method will substantiate the literature review by conducting a field work divided into three subsections: Field study on board military and civilian HSC, simulator tests at RNoN and interviews and questionnaire with navigators using ECDIS in their everyday work. The reason for this construction of research methods is to fret the research aim and its objectives from several angles. By observations on board, it will be revealed which methods are used in the day-to-day work of a navigator on board HSC. Observations will be done both on board military HSC and Civilian HSC carrying passengers, to reveal divergences. Simulator tests make it is possible to measure in a controlled environment how long it takes to detect an error in position sensor input to the ECDIS, and what methods are used to detect this error. The interviews and questionnaire will provide useful information of which methods the navigators say they use in optical control of ECDIS, which can be compared with all the observations done throughout the field work and with the literature review. The second part is done in the form of a questionnaire to measure if the system knowledge of the navigators is sufficient.

In the following there will be a description and analysis of the fieldwork and interviews conducted, which will be comprised in a synthesis of the findings at the end of this chapter. At the end of each description and analysis part there will be a subsection with highlighted findings.

4.1 Description and analysis of the observations on board

The observations on board were split into two parts. The first part consists of one week on board HNoMS Gnist[17]. HNoMS Gnist is a Skjold-class FPB, characteristics and operations conducted can be found in Appendix A. Several studies have been carried out on board the Norwegian FPBs (Bjørkli, 2007, Gould, 2009, Gould et al., 2006, Gould et al., 2008), which state the harsh environment and high demands for the OOW. It has been argued that the combination of high speed and the confined waters of the Norwegian coastline make the navigation on board the Norwegian FPBs one of the most demanding navigator jobs in the world (Bjørkli, 2007).

The second part consists of two days on board the Norwegian ship owner NorLed catamarans M/S Tidevind[18], M/S Tyrving[19] and M/S Tidebris[20] which is all owned by NorLed[21]. Tyrving and Tidebris are very similar HSC, while Tidevind is slightly smaller and newer, but it comprises the same navigation equipment.

The cruising speed of a military HSC is higher than a civilian HSC, and the crew size is larger. Military HSC always sail with two navigators. Most of the civilian HSC are operated with two navigators, but some with only one navigator. This is due to the legislation from the Norwegian Maritime Directorate (NMD, 2012), and are mainly dependent on ship size and machinery. Area of operation is similar, but military HSC patrol a larger area than civilian HSC in commercial traffic between A and B. Both military and civilian HSC use ECDIS, but manufacturers are different and integration varies due to different types of manufacturers of the INS.

4.1.1. Description and analysis of the observations on board HNoMS Gnist

The period on board HNoMS Gnist lasted for one week, and the main area of operation was the Northern Norway area of Lofoten shown in Figure 4.1.

[17] http://www.flickr.com/photos/jimbav/8649174398/
[18] http://no.wikipedia.org/wiki/MS_«Tidevind»
[19] http://www.marinetraffic.com/ais/shipdetails.aspx?MMSI=258130000
[20] http://www.marinetraffic.com/ais/shipdetails.aspx?MMSI=258108000
[21] http://eng.norled.no/Default.aspx?pageid=756

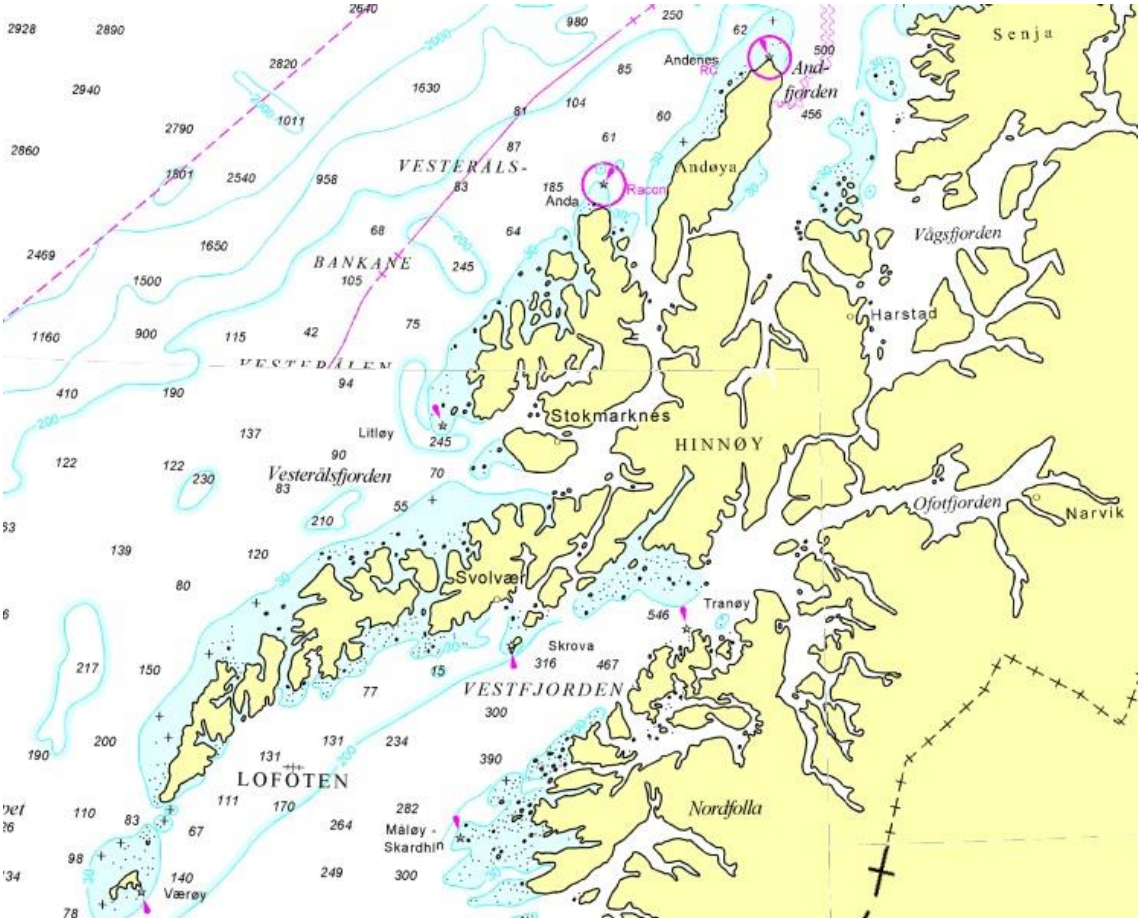

Figure 4.1 Area Lofoten

As seen in the chart in Figure 4.1 this is a demanding area for navigation with a multitude of islands, skerries and underwater rocks.

The field work also comprised a patrol from Northern Norway to Trondheim (distance 410 NM), shown in Figure 4.2.

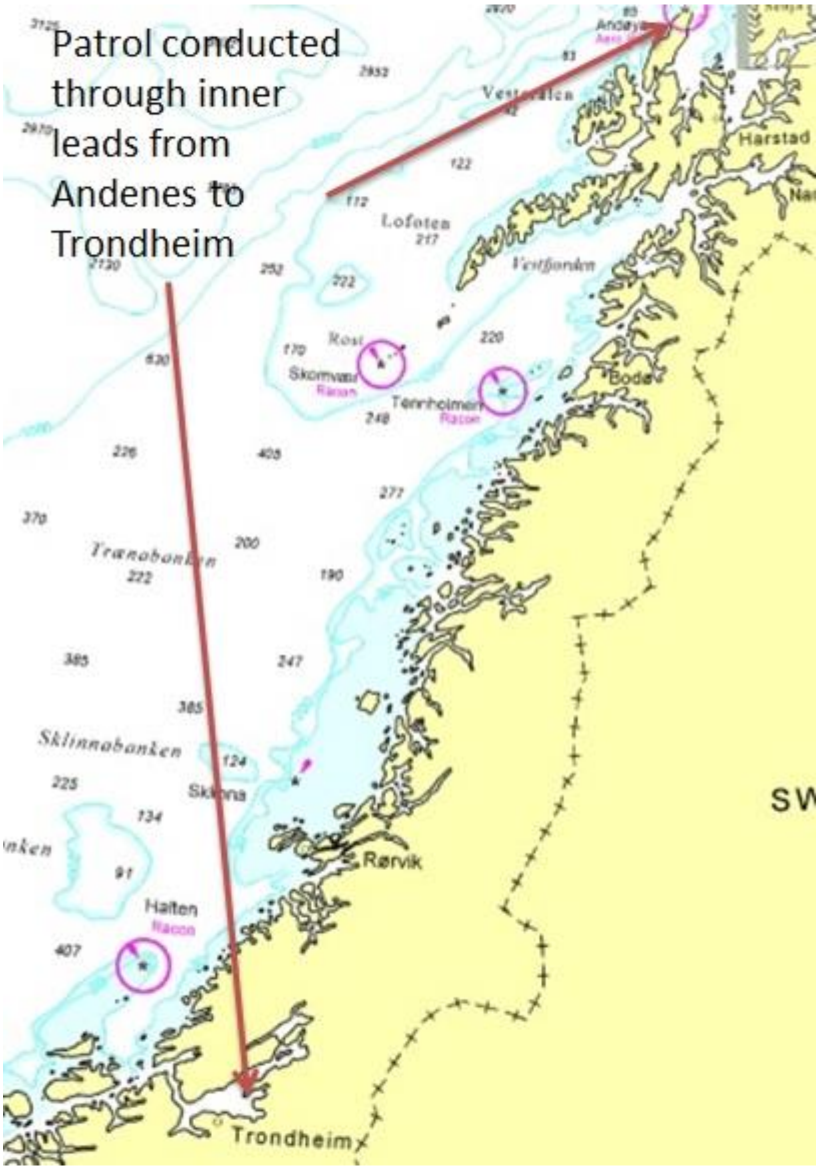

Figure 4.2 Patrol southwards

This area is also distinguished by its difficult navigation environment.

The navigation was conducted in daylight, since the sun never sets in the northern part of Norway.

The data was collected in all types of coastal waters, and mainly in speeds exceeding 40 KTS. Two navigation teams were observed, with an experience level spanning from one to eight years of experience as navigator on board an FPB. The field work report is given in Appendix B.

During the period on board there was no fall-out of GPS signal noted, even though the vessel visited fjords with steep mountains where only parts of the sky visible. In informal interviews, the crew expressed very little experience in fall-out of GPS expect when training in a simulator. Both crews had a small window on the ECDIS open which presented the HDOP value. The "normal" value was 1.1, and it was never seen below 1.5 giving the following position accuracy with the use of PPS (MoD, 2007, p. 30):

$$\text{Position accuracy} = \text{HDOP value x Accuracy of service (PPS vs SPS)} = 1{,}5\ x\ 5{,}9m = 8{,}85\ m$$

Most accurate data quality in ENC is ZOC B (50 meters), some areas with ZOC C (500 meters). During the observations ZOC was not commonly displayed on ECDIS, and there was no apparent procedure for displaying this feature.

Observed methods of control of ECDIS are given in Table 4.2 below.

	Navigation team 1	Navigation team 2
Visual control	Cross bearing[22]	Cross bearing
	½-bearing	½-bearing
	4-bearing	4-bearing
	Relative positioning[23]	Relative positioning
Conventional control	Radar overlay	Radar overlay
	Radar bearing and distance	Radar bearing and distance
	Control of HDOP values[24]	Control of HDOP values

Table 4.1 Methods of control HNoMS Gnist

The frequency of the different control methods is varying dependent on the character of the waterways and speed of the vessel. Most routes are planned by the navigator and validated by the OOW. The notation for the Norwegian Navy is used in all planning, with reference to Appendix D. When using the notation you will normally have a heading towards a fixed point, and an object to turn on abeam. This gives a

[22] Two lines of position: Heading point and abeam.
[23] Relative positioning meaning that the navigation team uses its relative height in the fairway to estimate the vessels position. E.g. when the vessel is passing under a bridge and when the vessel is in the middle of very narrow waters
[24] Small window displayed in bottom left corner of Multi-Function Display (MFD) on Kongsberg SM-10.

cross bearing on almost every leg of the planned passage, allowing the navigation team to constantly control the vessel`s position by visual sights. This is shown in Figure 4.4.

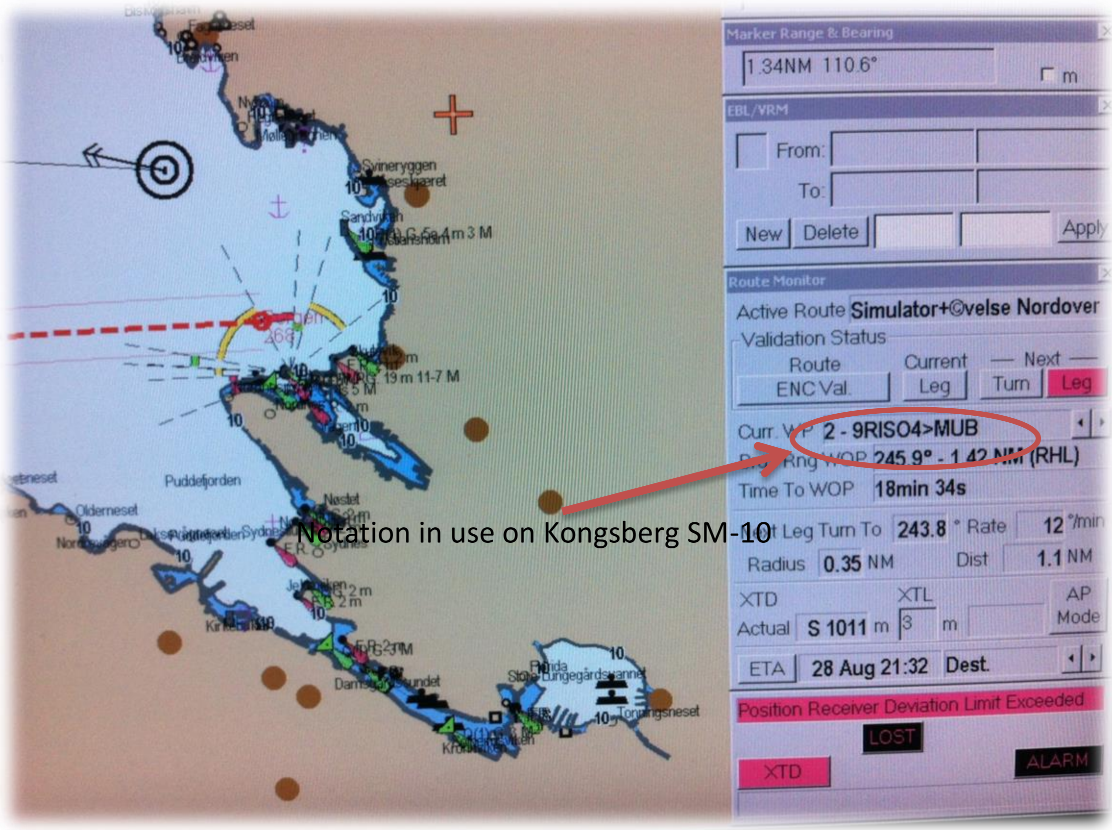

Figure 4.4 Use of notation in passage planning

MTBTS (2009) introduced the bridge manual with procedures for passage planning and procedures for communication, and it is used and well-known by all navigators on the Skjold-Class. This contributes to a coherent way of conducting navigation in all navigation teams on this type of vessel. Manuals and procedures relieve workload for the navigation team, workload which they can use to navigate even faster to achieve the end state of efficient navigation. A common manual and procedures for this type of ships also facilitate the fact that one navigator can change ship team, and still use the same known procedures to conduct efficient navigation.

In informal interviews with navigators on board the Skjold-Class, navigators highlight the navigation muster as an important event to keep focus on the methods of control of the ECDIS. The navigation team knows that they have to perform well in the navigation muster, so that keeps up a good focus on navigation and the navigation systems. The navigators also accentuate the use of a 1:1 simulator as essential in focused navigation training. When using the simulator, a specific aim for the given simulator exercise is known and trained on. After the exercise, feedback is given by experienced navigators and to each other by the navigators conducting the passage. With this type of simulator training improvement of navigation skills is gained for each navigation team. In a 1:1 simulator all the integration and interface are exactly the same as on board the vessel, which increases the realism in the training.

Common manuals and procedures, simulator training and continuous focus on education of new navigators from the Naval Academy contribute to high focus and skills in methods of control of ECDIS on board HNoMS Gnist.

4.1.1.1 Highlighted findings

1. Navigation training when arriving and while on board, with reference to Figure 4.3
2. Use of procedures and manuals
    a. Ease the workload for the navigator.
    b. Situation awareness on the bridge is made easier with common procedures and manuals.
        i. Two navigators cooperating to establish the same situation awareness.
        ii. Notification of alarms (read-out procedures).
    c. Manuals easy accessible where information about the systems can be found.
3. Each navigator plans their voyage with extended use of notation, with reference to Appendix E.
    a. ZOC values not assessed during planning or during voyage.
4. Methods of visual and conventional control, with reference to table 4.1.
5. System knowledge
    a. With reference to Appendix C, part 2.
    b. Uses HDOP value presented during the passage.
    c. Chart contour overlay from ECDIS on RADAR.
6. Use of simulator.

a. Focused navigation training with specific aim for each navigation team conducted in controlled environments in 1:1 simulator.
b. Conduct of navigation muster
    i. Keep up the navigation focus, and is a benchmark for the navigation team.

4.1.2 Description and analysis of the observations on board NorLeds HSC

The observations on board NorLeds HSC were divided into two, but the observations will be treated as one as there were no divergences in the way of conducting navigation on board the three different ships in the two different sailing areas. One day with observations and data collection conducted in each of the two sailing areas. The first observation was done in the area between Aalesund and Hareid on board M/S Tidevind, shown in Figure 4.5. The sailing route is 15 nautical miles (NM) one way.

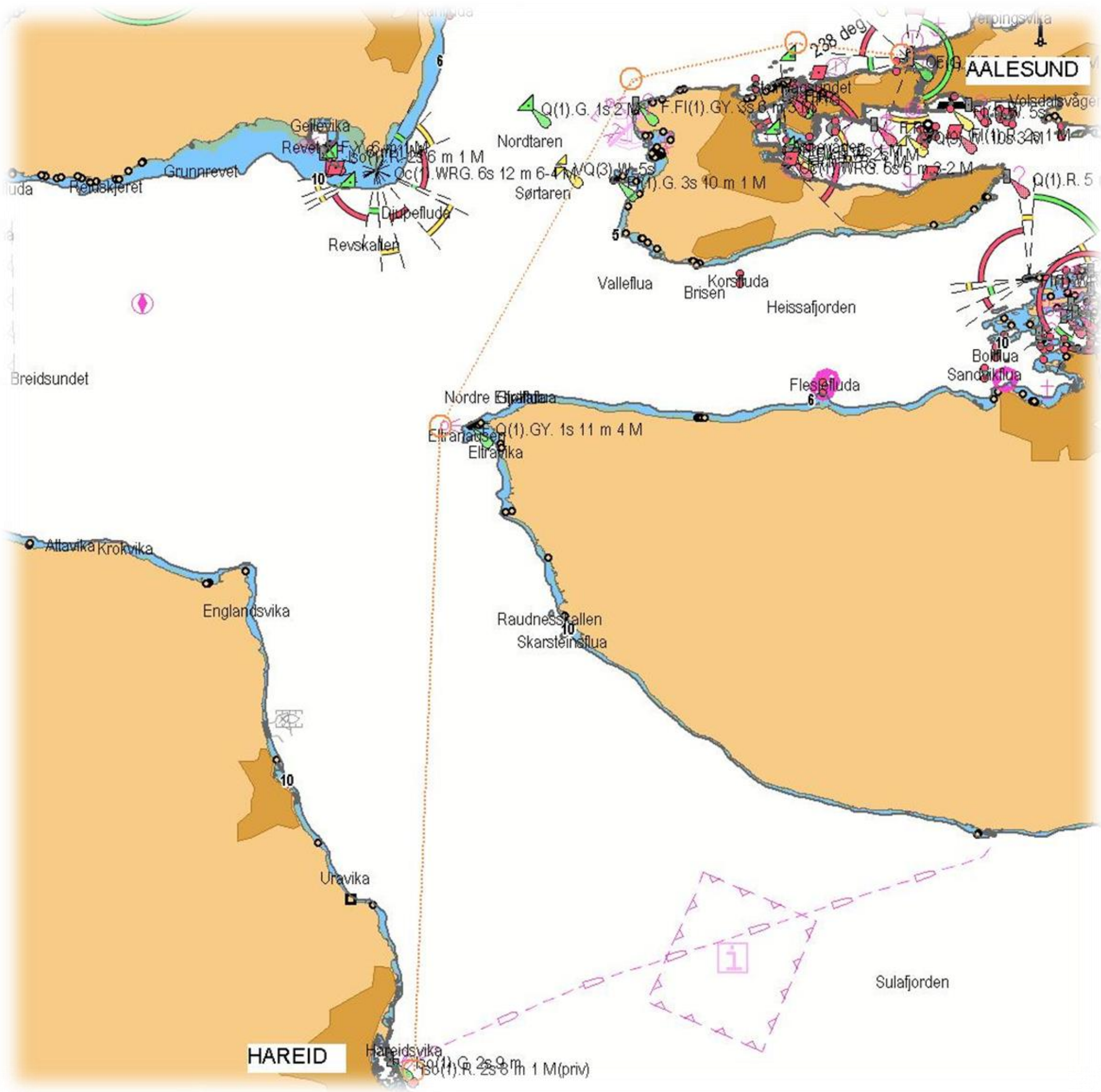

Figure 4.5 Chart from Aalesund to Hareid

The second part of the observation was made between Bergen and Leirvik on board M/S Tyrving and M/S Tidebris, shown in Figure 4.6 below. The sailing route is 50 NM one way.

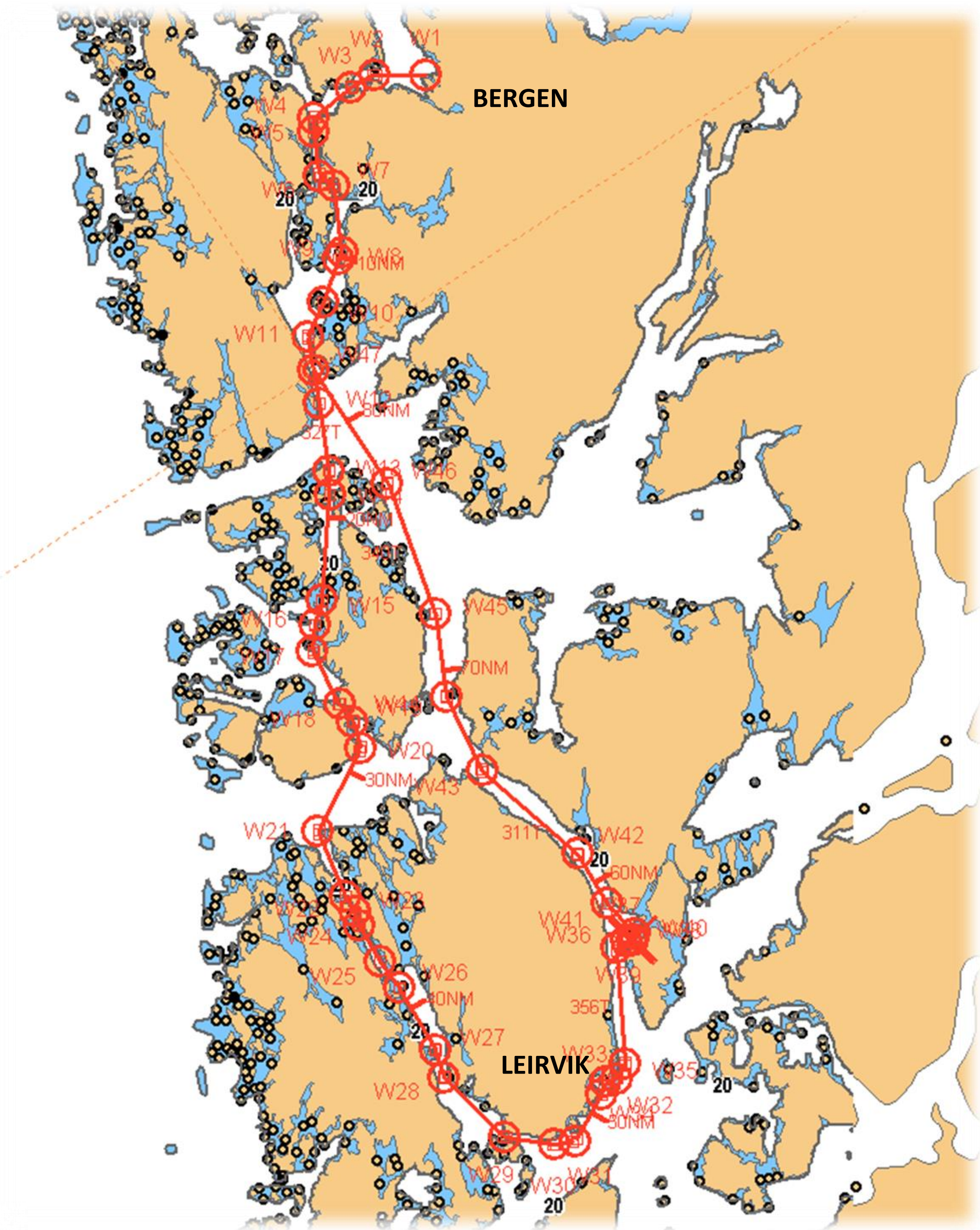

Figure 4.6 Chart from Bergen to Leirvik

Both areas are demanding environments for navigation. All observations were done in daytime and with clear weather and sea states not exceeding sea state 2[25].

The navigators on board NorLeds HSC were all above the age of 40 years, and had all more than 5 years of navigator experience. The route between Bergen and Stavanger

[25] Sea state is commonly used in the maritime world. For more information see http://en.wikipedia.org/wiki/Sea_state.

(Figure 4.6) is sailed four times a day[26], the route between Aalesund and Hareid (Figure 4.5) is sailed 16 times a day[27]. This provides the navigators of extended knowledge of the area.

Observed methods of control of ECDIS are given in Table 4.2 below.

	Navigation team 1	Navigation team 2	Navigation team 3
Visual control	Relative positioning	Relative positioning	Relative positioning
Conventional control	None	None	None

Table 4.2 Methods of control NorLed HSC

Planning of the routes was done by one navigator who distributed this to the rest of the vessels. There was no use of notation, and optical sailing principles such as using a heading marker and turning when an object is abeam was not used. The ECDIS was mostly used as an Estimated Time of Arrival (ETA) tool, which is crucial when keeping a tight schedule. There were no updates of the position in ECDIS by conventional or visual methods of control during the voyage.

Observations on board with regards to system knowledge is that the control methods of navigation are known to the navigators, but with a new tool as the ECDIS the navigators have an over-reliance in the system (GPS). The OOW might control the navigation subconsciously, but there are no procedures on this matter. NorLed did not want to distribute their procedures, and they are not known. If NorLed has procedures with regard to control of ECDIS, this is not being used on board. If it were made clear procedures of visual and conventional methods of control, and time was given to practice in a controlled environment (e.g. a simulator), this would be done automatically by the navigator and OOW during the passage.

4.1.2.1 Highlighted findings

1. Time pressure with regard to schedule.

[26] NorLed Timetable: http://www.norled.no/uploads/documents/HurtigbaatRuter/Hordland_2013/Flaggruten_Bergen_Stavanger.pdf

[27] NorLed Timetable: http://www.norled.no/uploads/documents/HurtigbaatRuter/More_2013/Hareid_Valderoy_Alesund_2013.pdf

    a. ECDIS used as ETA tool.
2. Route planning conducted as ETA tool, not as a tool to help the navigator with integrity checks and to conduct visual- and conventional control of the position sensor input to ECDIS (use of notation).
3. Second navigator has several tasks to fill.
    a. Seldom used as second navigator.
4. Procedures not distributed
    a. No evidence of clear procedures used by any of the navigation teams.
5. Long experience
    a. Know the area they are sailing in very well, but show little knowledge and interest in a "new" system such as ECDIS. Very low score on questionnaire with regards to system knowledge, reference to Appendix C.
6. No procedures or systematics when it comes to control of position sensor input to ECDIS.
    a. Only relative positioning used, reference to Table 4.2.
        i. Civilian HSC navigators not used to visual control methods.
    b. No conventional methods observed.

A finding from the field study on board military and civilian HSC is that there is a clear distinction between procedures and system knowledge from military to civilian HSC. There are several reasons for this, but the following needs to be highlighted:

1. More navigation crew members on board military HSC.
    a. More time for navigational tasks and planning.
2. More system knowledge amongst military navigators compared to civilian navigators (reference to Appendix C).
    a. A reason might be more extensive navigation training and courses for military HSC navigators, reference to Figure 4.3.
3. Procedures and manuals.
    a. Clear and given on military HSC, not observed distributed on civilian HSC.

i. This stress the importance of good procedures and manuals, which are known by the crew.

4. Use of simulator in navigation training.
    a. Focused navigation training in simulator, preferably 1:1 simulator if possible.
        i. Constructive feedback from experienced navigator(s) after each simulator session.

4.2 Description and analysis of the simulator tests

The simulator tests were conducted at the Royal Norwegian Naval Academy`s facilities in Bergen, Norway. The Royal Norwegian Navigation Centre has its own simulator department, which consists of six simulators. Details laid down in Appendix D.

The test consisted of five navigation teams. Two teams from the Norwegian frigates, two teams from the Norwegian Corvettes and one team of cadets from the Naval Academy. Their experience spanned from zero (cadets fresh out of RNoNA) to 8 years of sailing.

The scenario was to conduct a normal voyage from Bergen to Sognefjorden, area shown in Figure 3.1. This is an area with many islands, inlets, skerries and underwater rocks, and will be demanding for the navigation team depending on experience, weather conditions and speed.

The environment and weather conditions were the exact same for all navigation teams. Wind direction 350 degrees, wind speed 10 KTS. Direction of current 000 degrees (north), speed 1 KTS. Wave height 0.4 metres, with 30% overcast and good visibility.

After 30 minutes of sailing the GPS position sensor input was set to drift by 10 metres north and 10 metres east with 10 seconds intervals.

The aim of the exercise was to measure when the navigation teams discovered that there was an error in the GPS position sensor input, and which means were used to detect the error.

The results of the simulator test are shown in Figure 4.6 below.

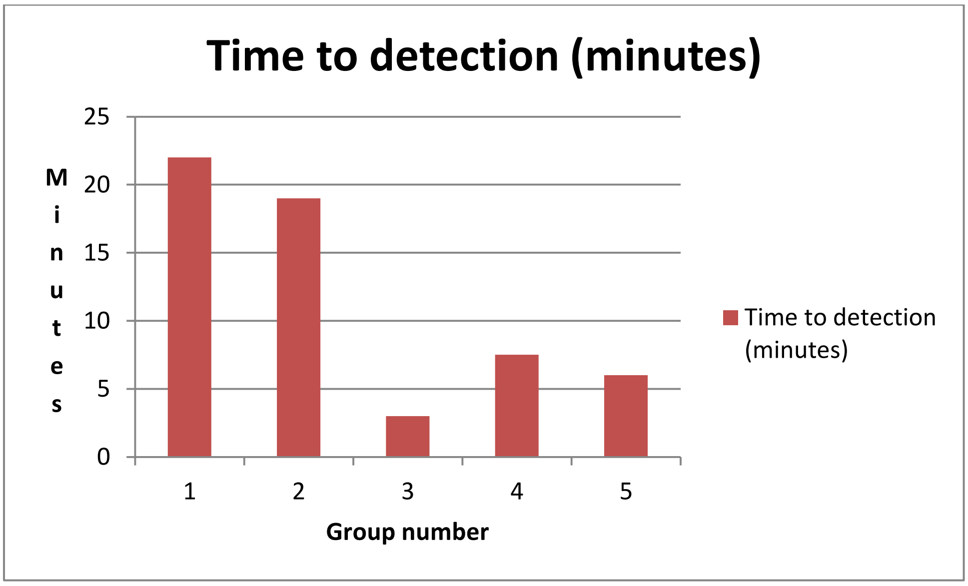

Figure 4.6 Time to detection of error in GPS position sensor input.

The average time to detection is 11.5 minutes. Median is 7.5 minutes. Since team 1 and 2 have significant higher values than team 3, 4 and 5, the use of median can be feasible. Standard deviation is 7,5, indicating that assuming an average distribution (68%) the time to detection will be between 4 and 19 minutes. It should be noted that the sample value is small, thus the average distribution should not be used. For further work it is recommended to conduct new tests with a larger amount of groups, and the collected data is in this thesis used as an indication.

When the error was detected, the deviation in position was as shown in figure 4.7.

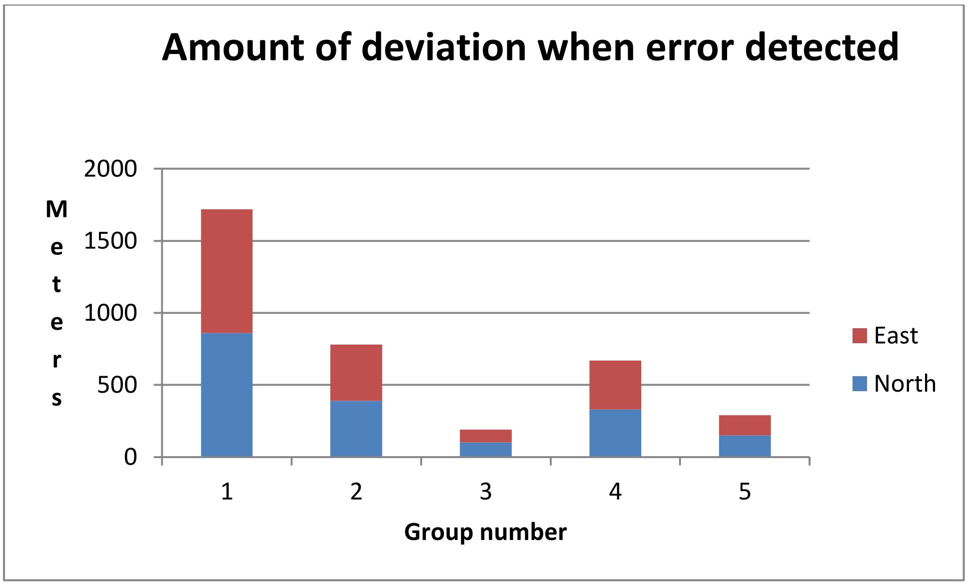

Figure 4.7 Amount of deviation when error detected

The average size of deviation is 730 meters (~0,4NM). Median is 670 meters (~0,36NM). Average and median concludes with almost the same values. Standard deviation is 271 meters, indicating that assuming an average distribution (68%) the amount of deviation when error detected will be between 459 and 1001 meters. It should be noted that the sample value is small, thus the average distribution should not be used. For further work it is recommended to conduct new tests with a larger amount of groups, and the collected data is in this thesis used as an indication. Information about the statistics from the simulator test can be found in Appendix H.

When looking at maritime accident reports in littoral waters[28] 730 meters is significant when it comes to accidents occurring. In narrow waters even short distances could enforce grounding, but this is dependent on the area of operation. It is therefore not advisable to quantify a specific amount when there is too much deviation. As an example, a position error of about 200 meters caused the HSC M/S Sleipner accident with 16 perished (NMAIB, 2000).

Table 4.3 presents which means were used to detect the error in the position input.

Nav Team 1	Nav Team 2	Nav Team 3	Nav Team 4	Nav Team 5
Visual sights Cross bearing	Visual sights Cross bearing	Chart contour overlay from ECDIS on RADAR	Visual sights Cross bearing	Chart contour overlay from ECDIS on RADAR
AIS vs. Radar	AIS vs. Radar	Visual sights Cross bearing	AIS vs. Radar	Visual sights Cross bearing
		Visual sights 4-bearing		Visual sights 4-bearing
		AIS vs. Radar		

Table 4.3 Means of detecting error in position input

With regards to Table 4.3 and the time to detection for the different groups, the use of chart contour overlay from ECDIS on RADAR points out as a main reason for quick detection of an error on the position sensor. Navigation team 3 and 5 used chart

[28] http://www.maib.gov.uk/publications/

contour overlay on RADAR console, which immediately gives the navigator a sight of drift in the system. This is shown in Figure 4.8 below.

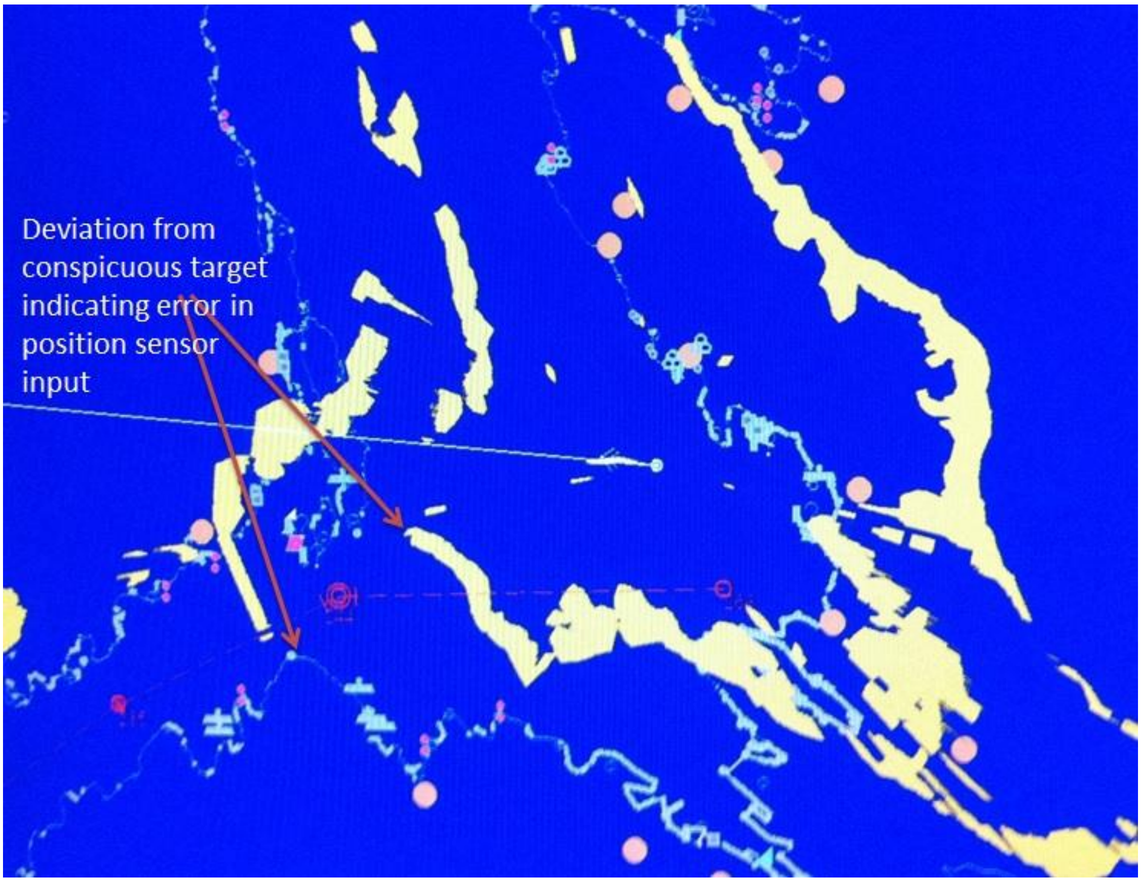

Figure 4.8 Drift in the system shown on RADAR console with the use of chart contour overlay

Four of the navigation teams also used the comparison of different track sensor inputs to evaluate whether or not there was a drift in the system (RADAR and AIS). This is shown in Figure 4.9 below which shows the deviation between RADAR and AIS, Figure 2.13 (page 42) is the same picture without deviation.

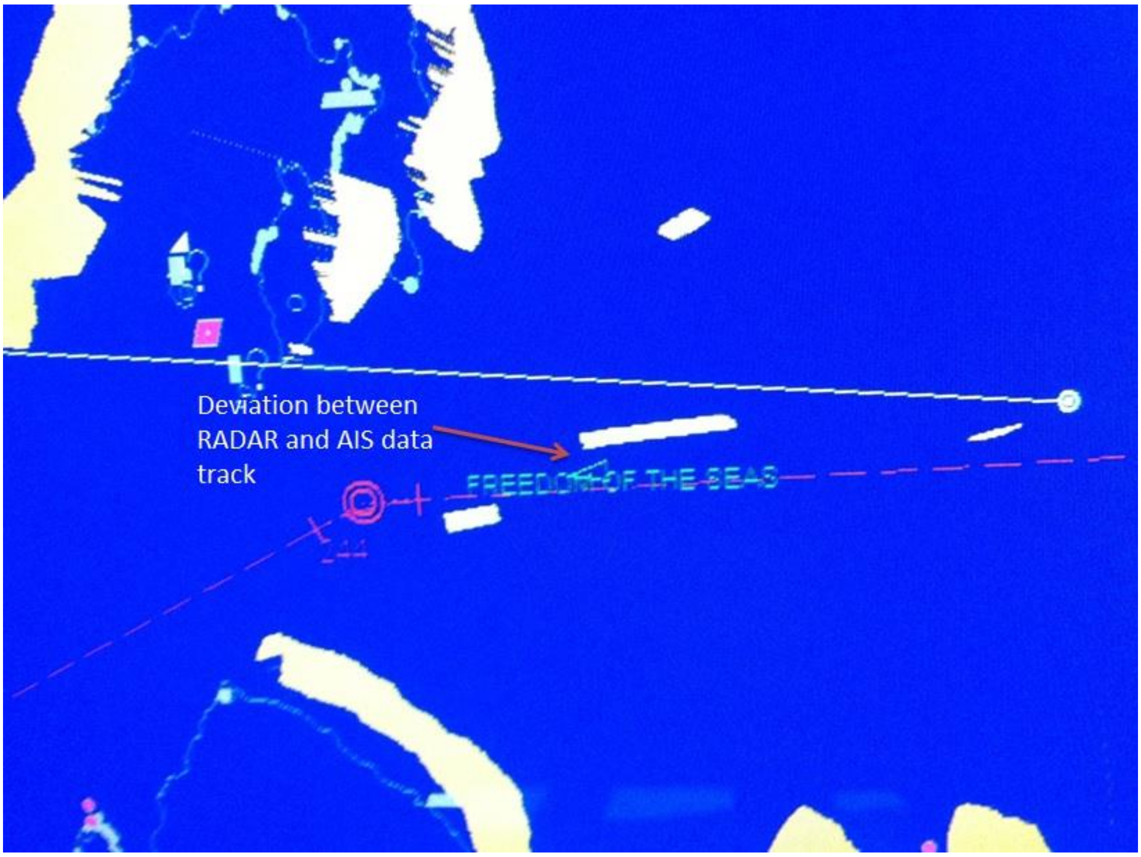

Figure 4.9 Comparing tracks to evaluate position sensor input.

When using this method it is essential that the navigator knows which position sensor input the different systems use, so that they can evaluate whether or not this is of importance. E.g. it might happen that the AIS GPS for some reason is faulty (technical reasons), while the ship`s primary GPS position sensor is healthy.

An interesting observation is that team 1, 2 and 4 all rely more on the position presented on the ECDIS than their own visual control methods. As an example Navigation Team 1 conducted four cross fix positions which the team discard because it was not coherent with the position fix given with the primary position sensor input (GPS) to the ECDIS. During all four position fixes there was an error in the primary position sensor, which resulted in the navigation team rejecting their own “good” visual control method which could have revealed the error in the primary position sensor. This shows the importance of always using a secondary position sensor to verify the position fix given by the primary position sensor.

Military units use Inertial Navigation Systems (INaS) for positioning as primary or secondary sensors. In the simulator test Navigation Team 5 tried to change from primary position input GPS to secondary position input INaS. It is fundamental for the user to know which position sensor input is weighted the most in the INaS, and if the deviation would affect the INaS as much as the GPS. INaS has a high weight on the GNSS system, and the amount of error in accuracy from the GPS will be the same with a bit of a delay for the INaS as well (Drum, 2013).

4.2.1 Highlighted findings

1. Long detection time when deviation on primary position input.
    a. Average of 11.5 minutes and 730 meters, median 7.5 minutes.
2. Efficient control methods for detection of deviation are the control methods which are easy to use and intuitive for the navigator.
    a. Visual control methods:
        i. Cross bearing
            1. Use of heading point and abeam point.
    b. Conventional control methods:
        i. Chart contour overlay from ECDIS on RADAR (intuitive).
        ii. Comparison of RADAR and AIS track data (intuitive).
3. Navigation team rely more on position given in ECDIS than their own visual control methods (discard “correct” visual position fix).
4. Thorough planning, with the use of notation, enhance navigator vigilance and will help the OOW control the position sensor input with visual control methods during the passage.

4.3 Description and analysis of the Interviews

The interview guide can be found in Appendix C, and is divided into two main parts. The aim of part one of the interviews was to find out what the navigators themselves find efficient in the control of ECDIS. The interviews have been beneficial in the thesis, when seen as a brainstorming amongst navigators to find out the current thoughts and practice on board regarding control methods of position sensor input to ECDIS. Part two consisted of a questionnaire regarding system knowledge and was carried out to gather data on the level of system knowledge amongst navigators. The questionnaire was elaborated in cooperation with fellow student Steinar Nyhamn (2013).

4.3.1 Part one

All navigators confirm that they control the ECDIS (question one), but use different ways and means of doing this (question two). All of the navigators use conventional control methods, and 65% (all military navigators) use visual control methods. This is shown in Figure 4.11 below, military navigators in blue, civilian in red.

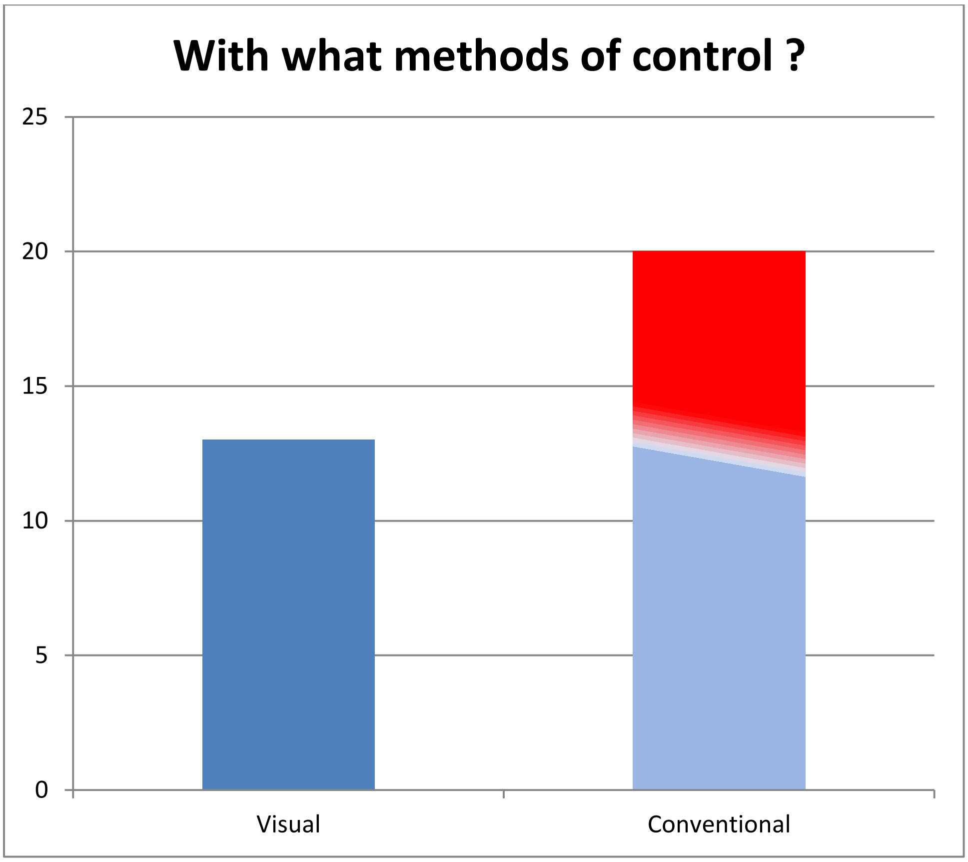

Figure 4.11 Methods of control

In Figure 4.12 all the different methods of control are gathered (question two and three). The findings have been divided into two categories, visual- and conventional control methods.

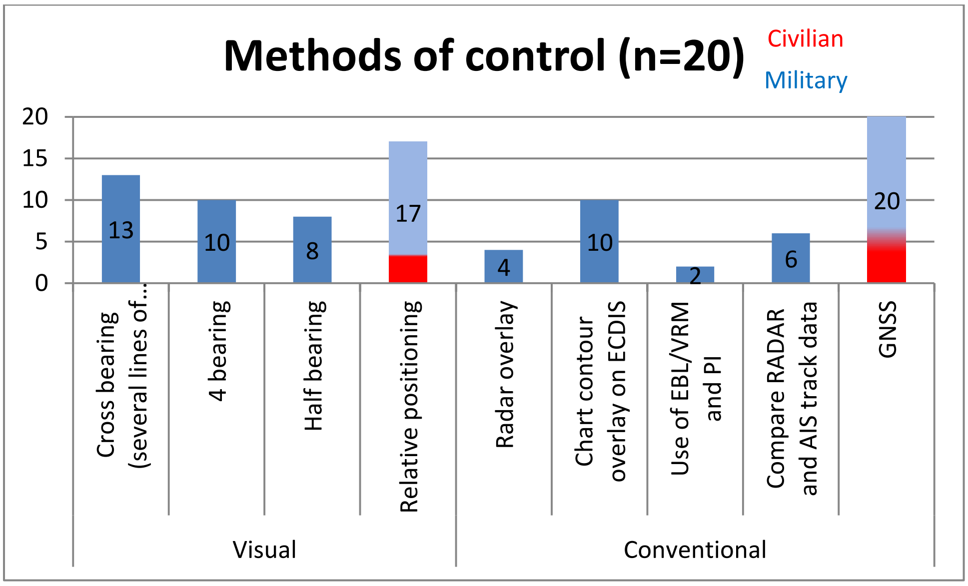

Figure 4.12 Methods of control of position sensor input to ECDIS

The findings from Figure 4.12 have been implemented in Table 4.5 in the latter part of this section, with regards to the advantages and limitations of the different methods of control.

An interesting finding when it comes to the difference between civilian and military users, is that the civilians characterize the GPS to be the most crucial mean of controlling the ECDIS. Military users emphasize the weakness in the GPS system, and accentuate the importance of having a secondary position control option of the ECDIS in addition to the GPS (or other GNSS).

Findings regarding system knowledge are that few know the advantages, limitations and possibilities of their systems[29]. Two questions regarding user level system knowledge were asked in part one of the interview. The findings show that the alarm “position deviation alarm” is misunderstood. Most navigators think that this alarm will alert them when their position sensor fails, but this is most likely not the case dependent on the set up of the alarm. On many systems they only have one position sensor, and thus there will be no deviation alarm if an error occurs. On other systems

[29] Question 4 and 5 regarding system knowledge, reference to Appendix C

the secondary position sensor input might be an Inertial Navigation System (INaS), which has the GPS as a primary position input in its position matrix, and thus the deviation alarm might not sound. This is because the GPS has a high weighting in the INaS position matrix, and the error in accuracy from the GPS will affect the INaS in the same way but with a small delay. It is essential to keep in mind that this is dependent on how many inputs the INaS has, and how the different inputs are weighted. This is an important issue that the navigators need to be aware of. No civilian vessels observed used INaS.

4.3.2 Part two

System knowledge amongst navigators was tested in part two of the questionnaire, with reference to Appendix C. The first part of the questionnaire was questions regarding system knowledge that the navigator is using in everyday work (score shown in percentage, with reference to Appendix C). This is shown in Figure 4.13, average score is 71%. Median is 77,5%, indicating a slightly higher score.

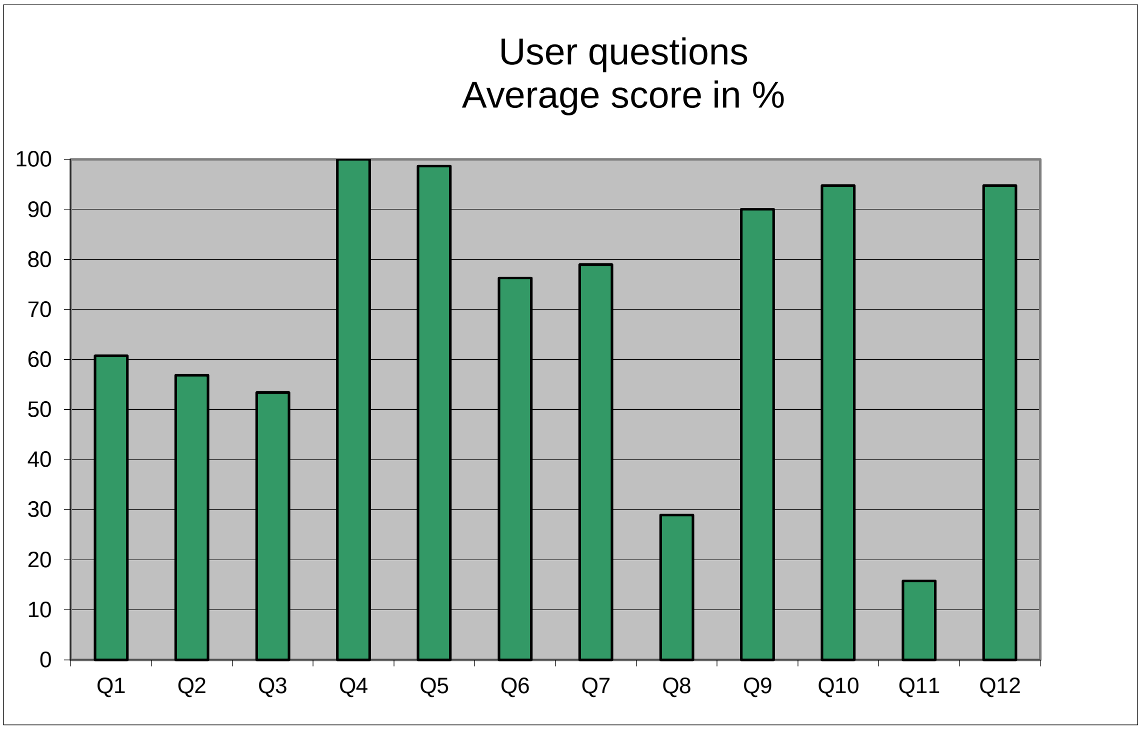

Figure 4.13 Navigator system knowledge

Figure 4.14 shows the system knowledge of the navigators in deeper technical level. Average score is 41%. Median is 43%, indicating the same or slightly higher score.

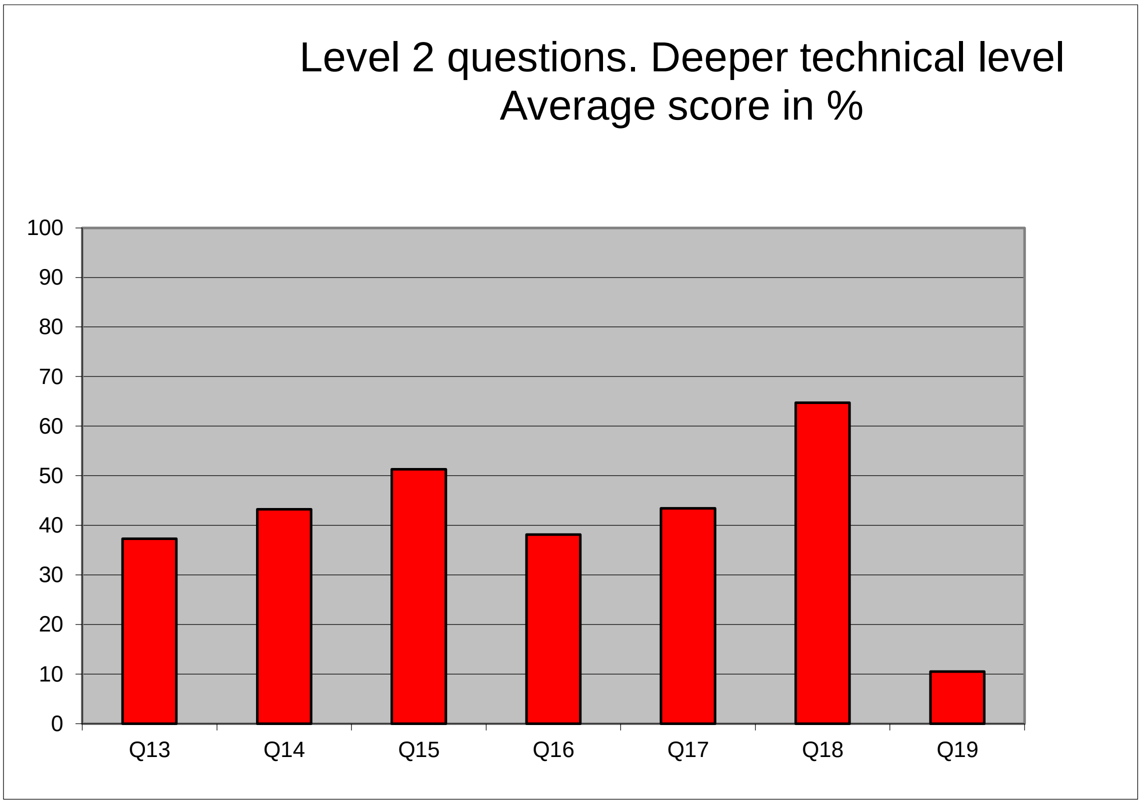

Figure 4.14 Deeper system knowledge amongst navigators

From Figure 4.13, 4.14 and Appendix C, the conclusion regarding system knowledge amongst navigators is that there is still a lot to learn for navigators. An average score of 71% on questions regarding user system knowledge of the systems which is operate daily is adequate, but the questions are of such importance concerning basic system knowledge that a high average score should be expected. When it comes to deeper system knowledge, the average score is 41% and is not sufficient. When the answer was explained most of them responded that they had not thought about this since they went to school. In most cases in the daily work of the OOW, deeper system knowledge is not necessary. Deeper system knowledge first arises when something goes wrong, and the system(s) stop working. It is then fundamental that someone on board the ship has the knowledge to troubleshoot the system to make it operational again. Perhaps it is too much to demand that every navigator should be at this level but it might be compulsory that the knowledge is present on each ship. On board military ships there are designated personnel who have higher skills and competence in deeper system knowledge of technical equipment used on the bridge and in the operation room. These personnel are not navigators, but engineers. How this challenge with regards to system knowledge competence on board should be solved in civilian shipping is outside the scope of this thesis. It has not been an aim in this thesis to set a certain acceptable score level. The accepted level of above 70% in user knowledge and 50% in deeper system knowledge is based on discussions with scholars at UoN, AUC, VUC and RNoNA. It must be noted that a quantification of an accepted passing level of the two questionnaires needs thorough consideration, and it has not been the aim of this thesis to analyse this in depth.

4.3.3 Highlighted findings

1. A gap is identified in methods of control between military and civilian navigators.
    a. Visual control methods only used by military navigators.
        i. Proper planning with the use of notation is of high importance to emphasize the use of visual control methods.
    b. Conventional control methods used by both military and civilian navigators.
        i. Different perception on the use of secondary control sensors. Civilian trust and rely on GNSS. Do not have a secondary position sensor input which they can do integrity checks towards.
            1. Civilian navigators are controlling the ECDIS, but with one conventional method: GNSS (GPS).
        ii. The use of relative positioning and chart contour overlay from ECDIS to RADAR most commonly used.
2. Deeper system knowledge amongst navigators not satisfying.
    a. System knowledge with system that is used in everyday work for the navigators score above 71% in average, which is adequate.
    b. Deeper system knowledge with systems used by the navigator score 41% in average, which is not adequate.
        i. The need for someone to have deeper system knowledge on board is fundamental.

4.4 Synthesis of Findings

From the fieldwork there is a pronounced border between military and civilian HSC navigation. The military have taken advantage of the use of manuals and procedures to formalize the control of positioning with ECDIS, and also use simulators to a larger extent to train and drill their navigation teams. There is also the inherent scepticism towards the GPS, because it is a system which can be turned off in times of war or crisis. This does not apply for civilian users. The last 20 years with GPS as the primary GNSS system has shown that it is a very reliable system (Moore, 2013), and thus the common civilian navigators have great confidence in GNSS such as GPS. This could also be the reason why the civilian navigators do not use notation when planning a voyage in the ECDIS. The notation is a very good and efficient aid when it comes to control of the ECDIS during the voyage. When using notation in passage planning, the OOW has been given a secondary method of control (first being the GNSS) without doing any extra work on the bridge.

In the simulator test the longest time to detection of an error was 22 minutes, while the average was 11.5 minutes. It is difficult to quantify how aggravating these numbers are, because it depends on the specific situation and surroundings of the vessel. However, an error of 1720 metres (almost 1 NM) is serious when not taken notice of. Especially when it comes to HSC operating in demanding littoral waters, a small error in the positioning sensor of 200 metres can be enough to ground a ship with reference to the Sleipner accident (NMAIB, 2000). The constant awareness and control of the positioning sensor is therefore of utter importance.

The demand for system knowledge has risen with the paradigm shift from paper charts to electronic charts and the use of ECDIS. Research done in this thesis show that the matter of system knowledge has not been properly addressed so far, this is also emphasised through IMO`s last revision of the ECDIS Model Course 1.27. With increasing technology and more complex IBS, the question should be raised if the navigator of the future is more a system operator than a navigator. The findings show that extensive system knowledge is required, but there is also a need for a navigator to conduct integrity checks either by visual or conventional control methods. It is shown in the field study that navigators that understand the system they use, also know why they need to monitor the system and what to look for with regards to integrity control.

With new technology it is important that all the navigators on board get sufficient instruction and training to use the system in a correct way. IMO has underlined the importance of familiarization, and both the ship owners and the navigators must address this matter. One way of doing this is through sufficient instruction and training when coming on board a new vessel, and this must be formalized through manuals or procedures. An example of a formalized training which is done with the Skjold-Class navigators is shown in Figure 4.3. The use of simulators to drill and train the navigation teams in the manuals and procedures are advantageous. A question also needs to be raised if the tuition of today is sufficient for the demands from the technology which meets a fresh navigator in his/her work on the bridge of a vessel.

There are several methods of control of the ECDIS which the software in the different ECDIS manufacturer systems are adapted for. The main problem is the user`s system knowledge when it comes to the practical use of these. In an HSC time is crucial, and the methods of control need to be time efficient and intuitive. Both the fieldwork and the simulator tests show that simple and intuitive methods, which are not time consuming but efficient, such as cross bearing (heading and abeam), control of overlay, presentation of secondary position sensor input and comparing different sensor tracks (RADAR and AIS) are efficient in detecting an error in the position sensor input. It is essential with thorough passage planning with regards to notation to ease the control of the passage for the OOW. The findings from the interviews show that the less time consuming the control method is, the more it is used. This is also supported when it comes to PSF studies where demand-capability balance is the main reason for accidents, and the Norwegian Maritime Directorate (NMD) studies of system errors in marine accidents. With quick and efficient methods of control, more time is released to address other important matters and thus to conduct safe navigation. Studies from the literature review show that the navigator has got more and more tasks to attend, especially with the introduction of IBS with several ship technical systems to monitor. It is thus fundamental to find ways of controlling the positioning sensors in an efficient way, but it must also be noted that the demands for civilian and military navigators might be different. Most civilian HSC traffic a route from A to B, which is sailed several times a day. Military HSC do not operate in a given area, but must be prepared to navigate in all navigable waterways. Other issue such as jamming is also a concern for the military HSC navigator. An example of this is GPS jamming attacks from North Korea aimed at South Korea.

The method of control found in the fieldwork and simulator tests in this thesis given in Table 4.5 point out simple cross bearings (heading and abeam), radar overlay and comparison of tracks from different sensors (RADAR and AIS) as efficient methods of controlling the position sensor input. The table is divided into visual- and conventional methods of control.

Visual Control Method	Advantage	Limitation
Cross bearing	Several lines of position will with proper training give an accurate visual position of the vessel. Efficient when using heading point object and object abeam. It is essential that the navigator is accurate when finding the ahead and abeam mark of the vessel to conduct cross bearings.	Time consuming when using several lines of position to plot in the ECDIS. Large ambiguity in accuracy if not trained properly (correct method conducted).
4-bearing[30]	Efficient way of controlling the position distance to an object.	Inaccuracy increases linear with speed (e.g. 60 knots 6 seconds on 0, 1 NM). Important with exact measurements. Should not be used when distance to object is more than 0, 5 NM (due to

[30] Further explanation in Appendix G

		accuracy).
½-bearing[31]	Efficient way of knowing the exact position when passing an object abeam.	Position is not known until object is abeam (position fix given when object is passed). Several error sources can affect the accuracy such as weather, current, ability to keep correct heading.
Relative positioning	Easy to use in narrow waters. For example when the vessel is in the middle of very narrow waters, or under a bridge. Easy, quick and accurate position fix. Accuracy dependent of confinement of the waters, and the accuracy is rapidly decreasing with open waters. Also known as *surmise*, but it is qualified surmise in adequate waters.	Only useful when you could accurately determine the vessel`s position by surmise. Be aware of human perception that can cause accidents. Emphasize secondary control methods when using relative positioning.
Conventional Control Methods	**Advantage**	**Limitation**

[31] Further explanation in Appendix G

GNSS (GPS, Galileo, Glonass, Compass)	High accuracy and good reliability. Revolutionized the craftsmanship of navigation, and is a very good navigation aid for the navigator.	Users rely too much on the system. When the system fails, the user will not take notice of it. The danger of this over-reliance is that the navigator will trust an erroneous GNSS position fix more than position fix by visual- or conventional methods.
Radar overlay on ECDIS	Can be compared to the traditional use of indexes on a RADAR, but with an interface from RADAR. The RADAR echoes are presented in the ECDIS giving the operator an intuitive information regarding the control of position sensor input chosen to ECDIS.	Disturbance in ECDIS picture. Too much information. Radar echoes hide crucial information for the navigator. Fundamental to know the limitations in the radar echo return and the radar parameters for the navigator (RADAR parameters).
ECDIS overlay on RADAR (chart contour)	The use of chart contour is the same as using parallel indexes (PI) on the RADAR (PI data will be extracted from ECDIS to use in the RADAR). S-57 charts (and thus chart contour) is the same on both the ECDIS and RADAR in the INS.	Demands more system knowledge from the navigator (RADAR parameters). Essential to choose a conspicuous target for certain determination of position.

	Intuitive way of controlling position sensor input chosen to ECDIS.	
Use of EBL/VRM and PI	Control of position sensor input chosen to the ECDIS.	More time consuming when there is not an interface between ECDIS and RADAR, because you have to extract data from ECDIS and then make use of it on the RADAR. If chart contour from ECDIS in RADAR is available this will do the same thing, but chart contour overlay is more efficient.
Compare RADAR and AIS track data	Intuitive presentation of possible deviation in position sensor.	AIS can be spoofed. AIS use its own built-in GPS. This is not the same as the ship`s primary GPS. User needs to be aware of that AIS GPS input is different from primary GPS position input to ECDIS system. This implies that an error could occur both in the AIS GPS and the primary GPS.
Other navigation systems (LORAN-C and eLORAN)	Yield an instant position fix, which with sufficient integration can be	Accuracy not as good as GNSS such as GPS. LORAN-C from 150 meters and

	presented on the ECDIS	upwards, eLORAN from +/-8 meters but is not carried out yet.

Table 4.5 Pros and Cons with different control methods of ECDIS

If readers want further explanation of the basic maritime definition and principle given in the table above, this is laid down in Martin Boehn`s MSc paper in Appendix A (Bøhn, 2011) and in this thesis in Appendix G.

5.0 Conclusion

The overall aim of the research project is how to improve and develop the control of position sensor input chosen to ECDIS on a High Speed Craft in littoral waters.

While writing this thesis there have been many questions regarding how much GNSS systems can be trusted. In the literature review the advantages and limitation of ECDIS, GNSS and augmentation systems are laid down. There must be no doubt of the fact that GNSS in general, and GPS in particular, is an important aid for navigators if used correctly. Since the introduction of GPS in the middle of the 1990s, it has been of great importance to navigation and has shown to be a very reliable system. It is also shown that GNSS has faults and limitations which the user must be aware of and therefore continuously monitor the system with regards to degradation. Especially in specific areas where satellite geometry is poor and can cause a degradation of the system, such as the Norwegian fjords. What must be stressed is the importance of having a secondary position sensor input which confirms the information from the primary position sensor input.

The literature review explains how regulations and legislation affect the use of ECDIS in HSC. Both national and worldwide statistics show a trend of navigational accidents slightly increasing after the implementation of ECDIS in 1995 and until today. This statistic is not sufficiently broken down to substantiate the assertion that the implementation of ECDIS has increased the amount of navigation accidents, but it is shown for the reader to be aware of the fact that a new technological asset without proper understanding and training is not a factor of success. This underlines the facts and findings that system knowledge and proper training are of great importance in order to use new technological assets such as the ECDIS correctly. If the user knows the system he/she is operating, the system knowledge understanding will increase and the navigator will know of the dangers with over-reliance in one system. Extensive system knowledge will also substantiate the need for secondary position control methods to verify the primary position sensor input.

Control of position sensor input has been divided into two: Visual and conventional methods of control. These two control methods have been analyzed and advantages and limitations with the different control methods are explained. It is fundamental that the navigators of today are aware of the importance of integrity checks, and that the integrity checks become a continuous process conducted on every watch. The frequency of occurrence of integrity checks has to be weighed against the confinement of the waterways, weather, systems operated and experience level of the navigator. The high importance of user-friendly and well thought out integration when designing an INS for HSC is accentuated. It is important to develop and organize the environment to minimize the workload on the navigation team. An example from the field study is that a user-friendly and convenient integration of the OBD to conduct several position lines is necessary to get a precise visual position fix.

With the paradigm shift from paper charts to electronic charts and the use of ECDIS, the demand for system knowledge has risen. The use of manuals and procedures has proven to be important for both system knowledge and to decrease workload of the navigation team. With new systems, new training is required and familiarization on board is underlined as an essential aspect of the implementation and understanding of ECDIS. The use of simulators is shown effective, and especially if the training is in a 1:1 simulator. Questions are raised on how much system knowledge the navigator should have, and it is clear that with the more complex INS systems of today and tomorrow, the demand for system knowledge is high. This must be properly addressed both by schools and ship owners. Especially procedures and manuals are shown to be efficient when addressing this matter. In field work, simulator tests and interviews, findings are that the user level system knowledge is adequate, but deeper technical level of system knowledge is not. With extensive knowledge of the systems operated, it would also be evident for the navigator that there is a need for continuous control of the primary position sensor input with secondary sensors or methods of control.

An interesting finding is that there is clear divergence between civilian and military HSC navigators, both in system knowledge and how they control the primary position sensor. Findings are that military navigators are more critical to the primary position sensor, and have better system knowledge than the civilian navigators. The reasons for this distinguish is not clear, but factors such as lean manning, navigation courses, simulator training, clear manuals and procedures and the pertinence of time to conduct navigation training are highlighted factors that might give the military navigators an advance.

There is clear evidence from both the literature review and field work of the fact that GNSS must not be seen as the full truth when it comes to navigation. The field work shows the importance of a secondary position sensor is crucial to continuously control the primary position sensor (which is GPS), by conducting integrity checks and using and monitoring secondary position sensor input. The fundamental difference between the paper chart and the ECDIS is the large extent of integration, different system manufacturers and the fact that working with a computer demands other capabilities and higher system knowledge from the user than working on a paper chart. As the ECDIS already has taken the place for paper charts in HSC, and on all larger ships within the year 2018, it is important that the marine world address this problem properly.

The ultimate aim of the navigator and the OOW is to conduct efficient navigation, and thus all of the above mentioned aspects need to be taken into account. The craftsmanship of navigation has been evolving ever since the first men started using boats, and it is of high importance that navigators continue to evolve with this constant change in demands and introduction of new technology and navigation aids.

5.1 Conclusion objectives

Objective 1: Identify control methods made for the use of ECDIS on an HSC (literature and field study).

- *a.* Literature review conducted in Chapter 2.
- *b.* Identified through field study on board military and civilian HSC, simulator tests and interviews with navigators.
- *c.* Addressed in chapter 4 Findings, with a summary in the following table:
  - *i.* Table 4.1 and 4.2, Methods of control military and civilian HSC.
  - *ii.* Table 4.5, Pros and Cons with different control methods of ECDIS.

Objective 2: Examine teams on board an HSC, and the control methods in use on the ECDIS (field study)

- *a.* Examined through field study on board military and civilian HSC and interviews with the navigation teams onboard.
- *b.* Addressed in Chapter 4 Findings, with emphasis on the following figure:
  - *i.* Table 4.1 and 4.2, Methods of control military and civilian HSC.

ii. Figure 4.12, Methods of control of position sensor input to ECDIS.

Objective 3: Evaluate critically different teams in a controlled environment (simulator) to see how position sensor input to ECDIS is controlled.

a. Evaluated through simulator tests conducted at RNoNA with five navigation teams.

b. Addressed in Chapter 4 Findings, with emphasis on the following table:

i. Table 4.3, Means of detecting error in position input.

ii. Figure 4.6 and 4.7, Time to detection of error in GPS position sensor input and Amount of deviation when error detected.

Objective 4: Explore the system knowledge and "best-practice" of navigators on board HSC (interviews and questionnaire).

a. Explored through interviews and questionnaire in cooperation with fellow student Steinar Nyhamn, with reference to Appendix C.

b. Addressed in Chapter 4 Findings, with emphasis on the following figures:

iii. Figure 4.13 and 4.14, Navigator system knowledge and Deeper system knowledge amongst navigators.

Objective 5: Formulate recommendations to methods of control of position sensor inputs to the ECDIS on a High Speed Inshore Littoral Vessel.

a. Found through the four objectives above, through field work on board civilian and military HSC, simulator tests at RNoNA and interviews with navigators.

b. Addressed in Chapter 4 Findings, with emphasis on the following table:

iv. Table 4.5, Pros and Cons with different control methods of ECDIS.

5.6 Summary of conclusion

Navigators of today have a much more technological environment which they need to address with both high system knowledge and traditional navigational craftsmanship. It is shown that primary position sensor can fail, thus it is fundamental to monitor and control the primary position sensor with a secondary visual or conventional control method. This thesis has shown the advantages and limitations with ECDIS and its position sensor inputs. The essential matter for the reader and every navigator is to be aware of the fact that every system needs to be controlled. This is done by integrity checks, and it is shown in this thesis that it could be divided into two sections: Visual- and conventional control methods.

The thesis also looks into the system knowledge of the navigators of today, and the findings show that system knowledge is not good enough to understand the advantages and limitations of the systems in use. There is also clear divergence in knowledge between military and civilian HSC navigators. It is important that the navigators of the future have got sufficient system knowledge to understand the systems they use in their everyday work. When the systems are understood, such as GPS, the navigator knows that he or she has to conduct continuous integrity checks with visual or conventional control methods to conduct efficient navigation and achieve a safe passage.

5.7 Recommended future work

Write an article to publish the findings in relevant journals.

Implementation of findings in relevant manuals in the RNoN.

Further explorations and investigation of the difference between civilian and military HSC navigation.

Development of the interface on Kongsberg SM-10 system with implementation of recommendations from this thesis and further investigations of user needs.

Evaluate the Norwegian Maritime Directorate HSC Course.

Analyse statistics with regards to ECDIS-assisted groundings.

INaS and error distribution from GPS.

In workshops conducted in August 2013 with scholars at Aalesund University College, it was decided that future work will be looking into which sensors and equipment are most used by the navigator. This will be done by using an EyeTracker[32] to register

[32] http://amo.hials.no/humanfactor/index.php/research/training/148-proj-eye-tracking

which sensor the eye of the navigator uses the most. This will be interesting with regards to further knowledge on which methods of control (visual or conventional) is most used and efficient in HSC.

"*This new ship here is fitted accordingly to the reported increase of knowledge among mankind. Namely, she is cumbered end to end, with bells and trumpets and clocks and wires... she can call voices out of the air of the waters to con the ship while her crew sleep. But sleep thou lightly. It has not yet been told to me that the Sea has ceased to be the Sea*."

- Rudyard Kipling

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Appendices

Appendix A Skjold-Class facts and figures

Courtesy of UMOE Mandal

The Skjold Class

Littoral Combat Ship

Area of Operation

- The Norwegian Coastal Waters and Economic Zone
- The international scene

RNoN Requirements

- A large number of relative small, cost effective vessels
- Designed for Surface operations in coastal waters
- A large weapon load compared to the ship´s size
- High transit speed

Highlighted Properties

- FRP materials designed for radar reflection and absorption
- Reduced infrared and optical signatures
- Electromagnetic interference and compatibility
- Shallow water capabilities
- Surface to surface missiles integrated in the FRP hull
- Low weight
- Reduced manning
- Excellent sea-keeping

High speed requirement in combination with superior sea-keeping, stability in heavy seas, large internal volume and low fuel consumption made the SES Concept a natural choice.

umoe

The Skjold Class

Littoral Combat Ship

Characteristics

Hull	• FRP Sandwich
Length o.a	• 47 m
Beam o.a	• 13.5 m
Draught	• On cushion 0.9 m • Off cushion 2.2 m
Crew	• 15 - 18 (Accommodation for 21)
Displacement	• 274 tons fully loaded
Propulsion	• 2 x 4000 kW Pratt &Whitney • 2 x 2000 kW Pratt &Whitney • 2 Rolls-Royce S-80 Water jets • 2 x 700 kW 12 cyl. MTU 183 for lift fans
Range	• 800 nautical miles
Speed	• 60 knots in seastate 0 • 45 knots in seastate 3
Stealth	• Reduced Radar Cross Section • RAS/RAM built into the Structure • Reduced IR signatures • Reduced magnetic signatures • Reduced underwater acoustic signatures • Umoe Mandal designed hatches and doors
Missiles	• 8 x SSM; The new Kongsberg Defence & Aerospace NSM
Gun	• OTO Melara 76/62 S.R.G.M.

Combat Management System

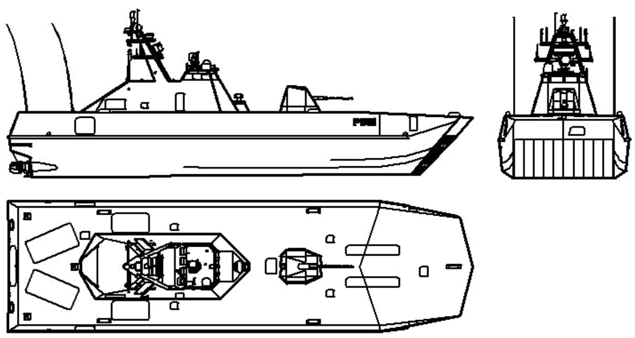
- SENIT 2000, developed and manufactured by DCN, in partnership with Kongsberg Defense & Aerospace

Sensors

- Thales MRR /3D NG surveillance radar
- SAGEM VIGY 20 Electro optical multi sensor
- Sofresud QPD Optical sight
- EDO RSS CS 3701 ESM
- Saab Tech CEROS 200 Fire Control Tracker
- Litton Navigation radar
- THALES IFF interrogator/transponder

Communications

- DCN Interoperable datalink (Link 11/16)
- Aeromaritime communication system.



umoe

Umoe Mandal AS
Member of the Ulltveit-Moe Group
Gismerøya, Servicebox 902, N-4509 Mandal, Norway
Tel: +47 3827 9200 Fax: +47 3826 0388
E-mail: mandal@umoe.no / Internet: www.umoe.no

Appendix B Field Work Report

Wednesday 5 June, M/S Tidevind[33]

Joined M/V Tidevind, a High Speed Passenger Ferry from roundtrip x2 between Aalesund and Hareid. Time on board 2 hours. Daytime journey, good sailing conditions, no precipitation, sun. Littoral waters. Normal traffic in the area. Picture of route and area:

Observations:

- No use of Radar
- No use of ECDIS
    - Use of CCTV for maneuvering on MFD for ECDIS use instead.
- Captain seems confident with his own knowledge of the waters. Does not state that he controls the journey with optical principles.
    - This is probably done, but it is not systematically, and there are no procedures of how to do it.
- Interesting observation when the captain is having dinner, one of the deck crew takes his place, and then the ECDIS picture is chosen on the MFD.
- The company owner does not want to distribute any procedures, so I do not know if this exists at all.

Friday 7 June to Friday 14 June, HNoMS Gnist[34]

Embarked the vessel in Andenes in northern Norway. Joined the ship for one week in different weather conditions. Professional team.

Conducted informal interviews with all members of navigation team. (5 persons)

Observed 2 different navigation teams during 5 days of sailing. Area Andenes – Trondheim. Distance sailed approximate 1500 NM.

Observations:

- Planning with optical control
    - OOW responsible for controlling and accepting the route which the ship is to sail.
        - Navigator planning and preparing for the route.

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[33] http://www.marinetraffic.com/ais/shipdetails.aspx?MMSI=258266500

[34] http://www.marinetraffic.com/ais/no/shipdetails.aspx?MMSI=259031000
http://en.wikipedia.org/wiki/Skjold-class_patrol_boat

            - What about a STANDARD SET OF ROUTES along the coast when you sail in high speed?
    - Using objects on the bow, and updating with objects abeam.
    - Optical principles such as:
        - Optical Bearings
        - 1/2 Bearing
        - 4-bearing
        - Use of sailed distance on the log
        - Relative positioning in narrow waters
            - E.g. under bridge, in the middle of very narrow waters (say 50 metres on each side of the ship, it is easy to state that the ship is in the right position using optical relative positioning).
- The use of Radar
    - Overlay from ECDIS on Radar very useful (land contours).
- Use of EOMS (laser bearings)
- In high speed, sailing in a team (as in a cockpit of a plane)
    - OOW (Officer of the Watch) and Navigator.
        - Navigator conducting all the navigation, OOW controlling and has VETO if needed.
        - OOW the senior officer with the most experience
            - On the Skjold-Class there is a course that all OOW have to conduct and pass to become OOWs.
- Navigation is just one of many roles the navigator has to fill.
    - Navigation principle has to be trained
        - Skjold-Class has yearly navigation checks on its crew, conducted by the Norwegian Corvettes` Training Centre.
- Awareness of which control- and automation mode the ship is in.
    - Control mode: Optical control, optical and radar control, radar control, optical and/or radar manual mode (no GPS input).
    - Automation mode: Manual, Autopilot local mode, Autopilot course mode, Autopilot heading mode, Autopilot WP mode, Autopilot track mode.

Simulator tests Sunday 16 June – Tuesday 18 June

Five navigation teams (2xCorvette, 2xFF, 1xCadets) sailed the same route from Bergen to Sognefjorden. 1 hours duration. Same preplanned route. 30 minutes with GPS input, 30 minutes without. Aim is to see when the navigation crew noticed the fall out of GPS, and what factors resulted in the findings.

After 30 minutes the drift on the GPS was set to 10 meters North and 10 meters East every 10th second (after 10 seconds 10 metres north, after 20 seconds 10 metres north and 10 metres east and so on).

Group 1:

FF.

Navigation team experience: OOW 4 year (total 7 years). Navigator just trusted as OOW, experience 2 years.

Speed 18-25 knots (dynamical use of speed with regards to the restrictions of the littoral waters.

22 minutes after drift started the navigation team states that there is something wrong with the navigation equipment (minute 52 of the test). The drift is then 860 meters in north and east direction (this is due to the instructor setting 10 meters drift in north AND east direction every 10 second).

Reason for noticing:

- Optical principle (object which was supposed to be abeam was not there).

Position Deviation Alarm not noticed due to many alarms not acknowledged.

Group 2

FF

Navigation team experience: OOW 1 year (total 4 years). Navigator 3 years (also OOW just trusted to be one).

Speed 12-15 knots.

19 minutes after drift started the navigation team states that there is something wrong with the navigation equipment (minute 49 of the test). The drift is then 390 metres N/E.

Reason for noticing:

- AIS tracks big offset compared to radar tracks.

- Optical principles.

Position Deviation Alarm not noticed due to many alarms not acknowledged.

Groups 3

Corvette

Navigation team experience: OOW 1 year (total 4 years). Navigator 2 year.

Speed 55 knots.

3 minutes after drift started the navigation team states that there is something wrong with the navigation equipment (minute 33 of the test). The drift is then 100 meters north and 90 meters east direction.

Reason for noticing:

- Optical principles (object on the bow and abeam).
- ECDIS overlay (land contours) on Radar.
- Position Deviation Alarm after 6 minutes (drift 244 metres).

Group 4

Cadets just finished from the Royal Norwegian Naval Academy.

Navigation team experience: OOW 0 year experience. Navigator 0 year (just finished school).

Speed 20 knots

11 minutes after drift started the navigation team states that there is something wrong with the navigation equipment (minute 41 of the test). The drift is then 330 meters north and 340 meters east direction.

Reason for noticing

- Indication of error after 7 min from parallel index from radar
    - Radar overlay
- Indication of error stated by navigation team after 7.30 min by comparing AIS and Radar tracks
- Indication on error from optical bearings after 8 min.
- Position deviation alarm after 9 min
- Stated that there is an offset and changed to manual mode after 11 minutes.

Group 5

Corvette

Navigation team experience: OOW 2 years (total 7 years). Navigator 2 years.

55 knots

11 minutes after drift started the navigation team states that there is something wrong with the navigation equipment (minute 41 of the test). The drift is then 330 meters north and 340 meters east direction.

Reason for noticing

- Indication of error after 3 minutes due to radar overlay (error Is 80 meters north, 70 metres east)
- Indication of error after 4 minutes due to optical principle (object abeam)
- Error stated and switched to manual mode after 6 minutes (150 meters north, 150 meters east)

Observations:

- Position Deviation Alarm
  - What is it really, and is it the same on all systems.
  - Change between navigation inputs
    - Depending on type of vessel, GPS 2, INS, LORAN C, manual etc..
- Radar Overlay
- Use of optical principles
  - Training!
  - Stopwatch?
- Passage planning and use of notation eases the workload on the navigator.
  - Easier to notice if there is an offset by comparing optical principles with the ECDIS.

Conducted informal interviews with all navigation teams.

Wednesday 20 June, onboard M/S Tyrving and M/S Tidebris

Observation of navigation team from Bergen – Leirvik – Bergen.

Sailed distance 200 nm, speed 30 knots. Time onboard 6 hours. Changed ship at Leirvik from Tyrving to Tidebris. Clear weather, seastate 1, NW 7 knots wind.

Observations:

- High Speed Passenger Ferries operate the same area, and have very high knowledge of the waters which they operate in. As a result of this they use their own knowledge of the waters, and mainly use the ECDIS for ETA calculations.
- Bigger passenger boats have a navigation team, but due to the need for the navigator also being a decksmate and ticket seller, normally there is only one person on the bridge.
    - I assume that when the weather is poor and there is need for it, they use both the navigators on the bridge.
- Radar is not used in good weather.
- AIS only used if they feel the need.
- They do not have a procedure or manual which they use (same response in every situation), so it seems a bit random how the passage is conducted.
- One person has made the route. No use of notation.

Conducted interviews with both navigation teams (4 persons).

Appendix C Interview questions and answers

Part 1

Conducted interview with 20 persons.

Interview questions

1.
    a. Do you control position sensor input to ECDIS?
    b. With what means of control (separated into visual and conventional method of control)
2.
    a. With reference to q1b: What methods of visual control do you use?
    b. With reference to q1b: What methods of convenitonal control do you use?
3. Which method of visual control do you assess to be the most efficient?
4. What is position deviation alarm?
5. (is it possible with a fall-out of GPS?)

Findings

<u>Question 1a:</u>

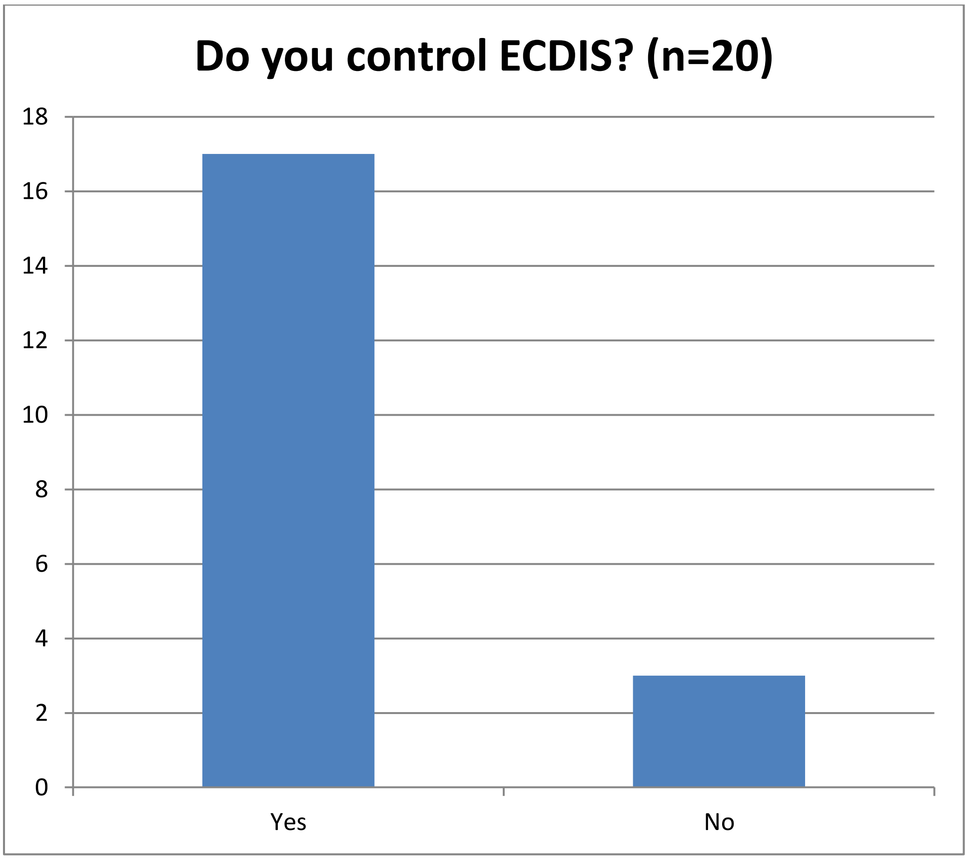


Figure 6.1 Control of ECDIS

Question 1b:

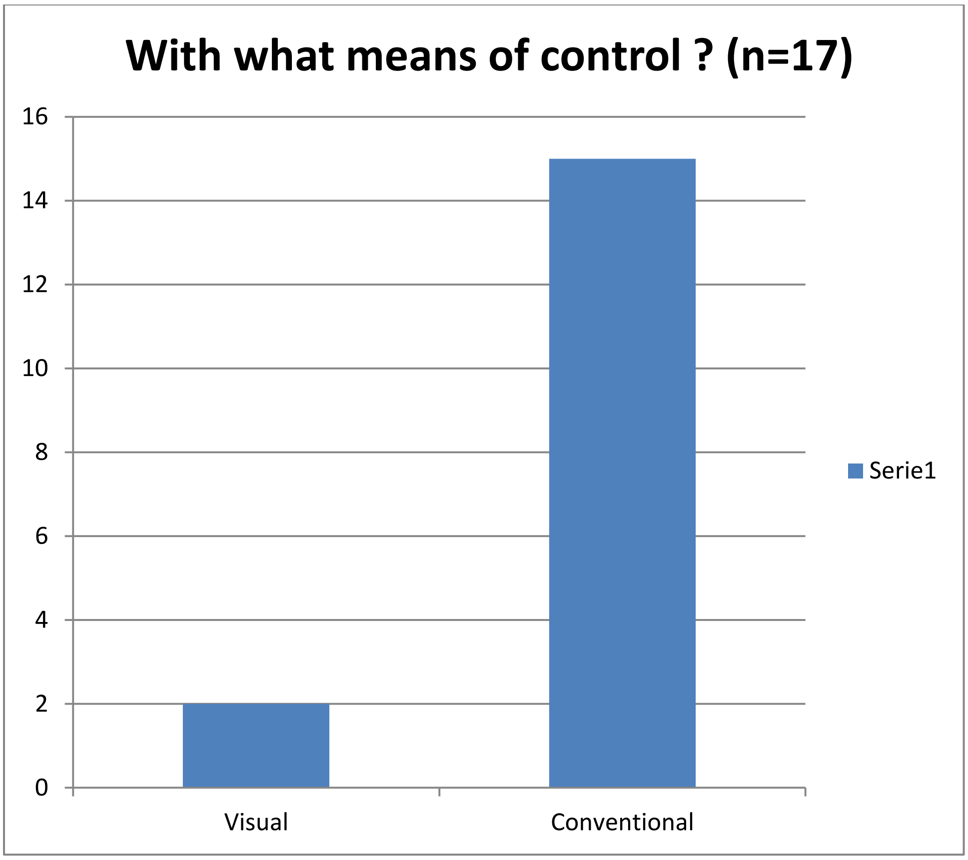


Figure 6.2 Means of control

Question 2:

Method	Type	Amount
Visual	Cross bearing (several lines of position)	13
	4 bearing	10
	Half bearing	8
	Relative positioning	17
Conventional	Radar overlay	4
	Chart contour overlay on ECDIS	10
	Use of EBL/VRM and PI	2
	Compare RADAR and AIS track data	6

Table 6.1 Methods of control

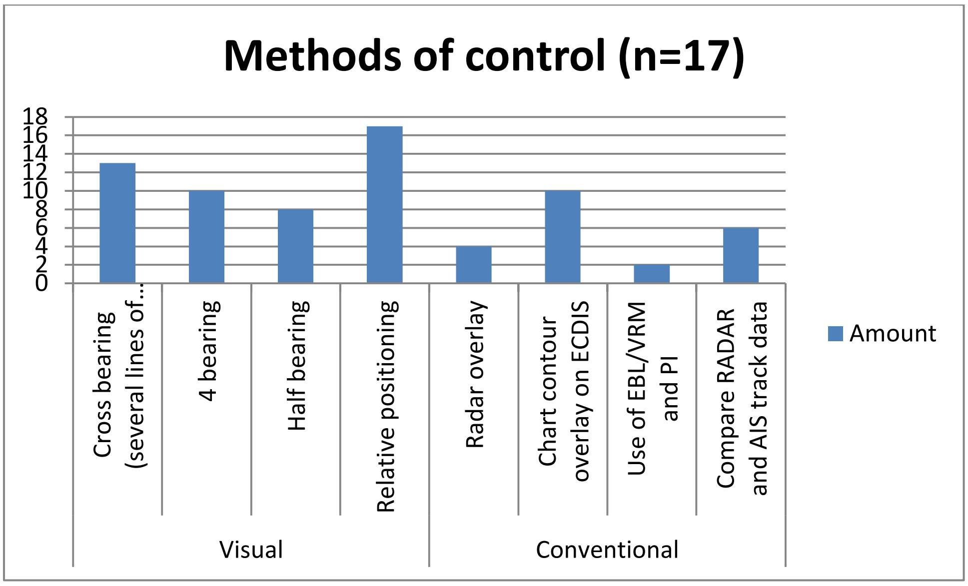


Figure 6.3 Methods of control

<u>Question 3:</u>

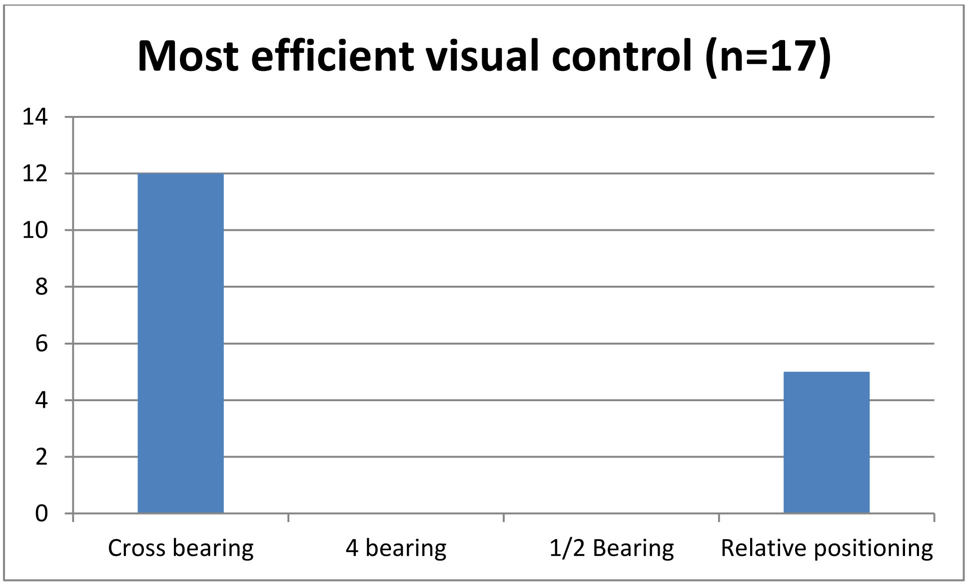


Figure 6.4 Most efficient visual control

<u>Question 4:</u>

Only four interview objects (20%) did understand the correct meaning of position deviation alarm.

Seven interview objects (35%) got It partly correct, but did not understand the whole meaning and advantages and limitations with the alarm.

Nine interview objects (45%) did not know what the position deviation alarm is.

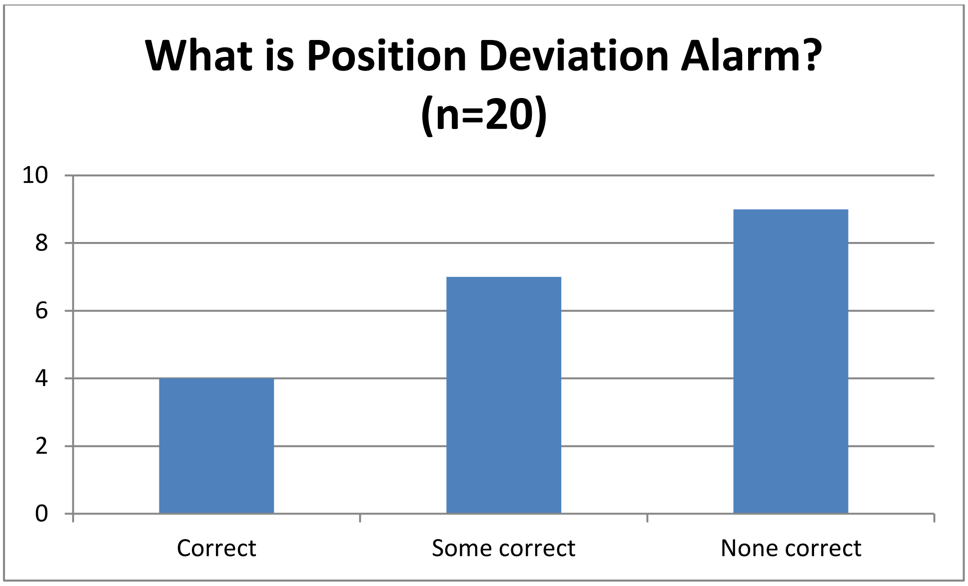


Figure 6.5 Position deviation alarm

<u>Question 5:</u>

During discussion with the interview objects, most finally agreed that there are some flaws with the GPS that we need to be aware of. Nevertheless, the graph below show that 60% thinks that the GPS does not fail.

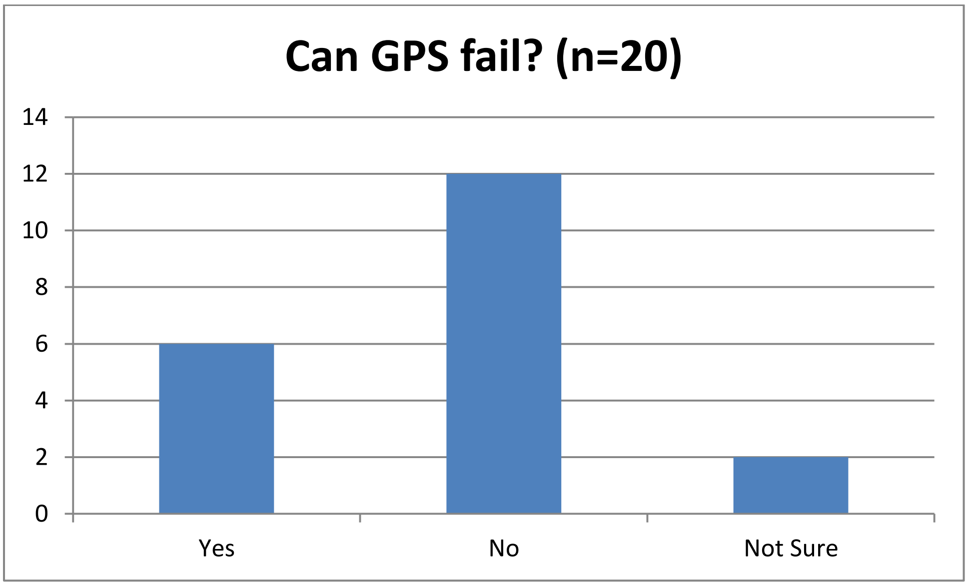


Figure 6.6 Can GPS fail

Part 2:

Conducted questionnaire with the aim to disclose system knowledge amongst navigators. Divided into two sections. Section 1 regarding user system knowledge with systems in use in navigators everyday work. Section two with regards to deeper system knowledge with systems in use in navigators everyday work

Questionnaire

This is done in cooperation with fellow student Steinar Nyhamn.

Type of vessel (circle): Frigate, FPB, Mine, Others:
Number of years experience as a 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, that's 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 Table.	
1	Explain how the mode NUP / FT ?	1. Land is moving. 2. Is confined to a square on the screen. 3. North up		

nr	Question **RADAR/AIS CAT 1, User level**	*"Model answers"*	Answer	%
		4. Own pos fixed 5. True vector and trails. 6. A mix of true and relative mode 7. Radar is not putting trails on echoes that have opposite course and speed as own ship		
2	Pros and cons of mode NUP / FT?	1. Depending good input log and gyro. 2. Easier to distinguish vessels from other echoes. 3. No need to reset own pos		
3	How is 9 Ghz radar distinguished from 3 Ghz?	4. Shorter wavelength better resolution 5. SART and Racon 6. Smaller antenna 7. 3 Ghz is better regarding rain and sea clutter		
4	Name minimum three features/controls of the radar that are important to optimize the radar picture	8. Gain - video gain 9. Rain- rain clutter control 10. Sea - sea clutter control 11. Puls length 12. Tune - tune control (kan nevne pulslengde og tuning men tuning bør være i auto)		
5	When do you use "rain clutter control" and "Sea clutter	13. Sea clutter control : See targets and objects through		

nr	Question **RADAR/AIS CAT 1, User level**	*"Model answers"*	Answer	%
	control"?	waves especially close to own ship 14. See targets and objects through rain		
6	What is the conditions for the "COLL alarm" to go off?	15. **Coll:** Collision alarm. One or more of the tracked targets are violating the CPA/TCPA limits.		
7	What is automatic acquisition	16. A pre determined area where radar targets are automatically tracked and AIS targets are activated.		
8	What is "Fusing of Target"	17. One vector will be presented on basis of 1 ARPA and 1 AIS target 18. Dependant of values set by operator		
9	What impact has antenna rotation speed on target detection? Advantages / Disadvantages	19. Slow = number of pulses on the target 20. Fast = faster update		

nr	Question **RADAR/AIS CAT 1, User level**	*"Model answers"*		Answer	%
10	Name at least 3 static and 3 voyage data?	21. MMSI 22. Call sign 23. Name 24. IMO number 25. Length and beam 26. Type of ship 27. Location of position fixing antennas on the ship 28. (Height over keel)	29. Ship's draught 30. Hazardous cargo type 31. Type of ship 32. Destination 33. ETA (Nr persons on board)		
11	MMSI number is visual on an AIS track, but not the name. Why do you think this is?	34. Name is static data that is only transmitted every 6 min. 35. MMSI is with all the messages to identify the message			
12	When a target is tracked, does it show True and relative vectors?	36. True if in true modes (including NUP/FT) 37. Otherwise relative			

Nr	**Question: RADAR / AIS CAT 2, Technical, system understanding**	*”Model answers”*	Answer	%
	~~Hvorfor har fartøyet to forskjellige nav radarer (teknisk og ytelse)?~~ ~~Skjold: Hvorfor er x(i) 9Ghz bånd radar valgt som eneste~~	*~~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?	38. Target or not target, permanent or moving 39. Target = yes. Calculate course and speed from point to point calculation, Rough large search area. 40. Nav filter: accurate track based on more data. Reduces the search area. Courses are lagging behind when target turn 41. If the target is not found after a certain number of scan = lost track		
14	“Radar AIS are complementary technologies that enhance the safety of navigation”. List the strengths and weaknesses of each technology to	Radar vs. AIS: 42. Rely on own system vs. no control		

Nr	**Question: RADAR / AIS CAT 2, Technical, system understanding**	*"Model answers"*	Answer	%
	support this statement.	43. Ship relative and sea stabilised vs. SOG-COG 44. Difficult to jam vs. easy to jam via GPS 45. Clutter vs. No clutter 46. Line of sights vs. behind obstacles 47. Lagging behind when speed/heading changes vs. rapid update. 48. Only Heading and speed vs. lots of data		
15	How does automatic acquisition work?	49. A zone is designed around own ship 50. Targets entereing zone will be auro tracked 51. AIS targets entering will be activated 52. Can use barrier lines to avoid land		
16	Explain how Rain-rain clutter control and Sea - sea clutter control works, technically.	53. Sea: logarithmic adjustment of gain. Reducing gain more close to vessel 54. 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.		

Nr	**Question: RADAR / AIS CAT 2, Technical, system understanding**	*"Model answers"*	Answer	%
17	What is tasks of the GPS receiver in the AIS?	55. Synchronizing transmission 56. Reserve position of the vessel		
18	Which sensors are connected to the radar?	57. Log 58. GPS 59. GPS Heading, 60. Gyro heading, 61. AIS 62. Echo sounder 63. Other		
19	An AIS track with same name jumps from a echo to another. What could be wrong?	64. They have the same MMSI number (e.g.the sjøbjørn of a CG)		
	Have you ever used automatic acquisition	YES / NO		

Table 6.2 Questionnaire

RESULTS:

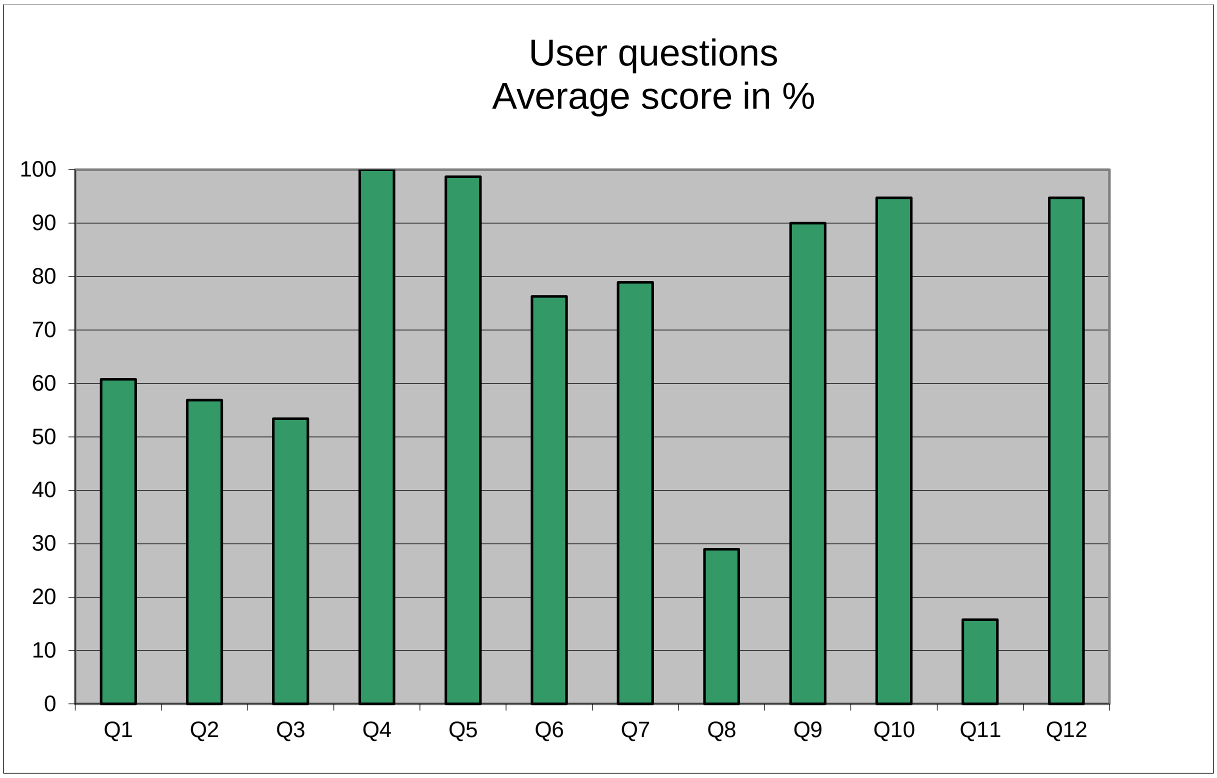


Figure 6.7 User questions average score

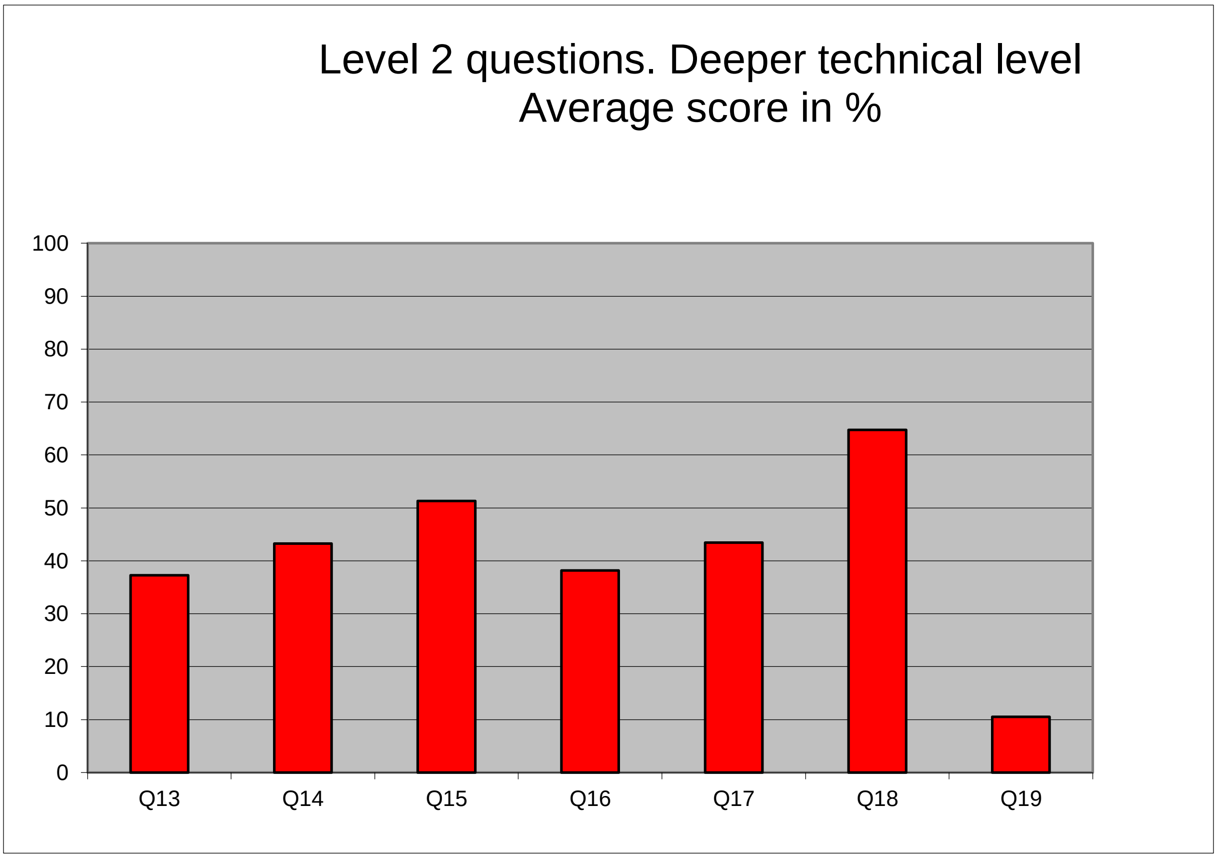


Figure 6.8 Deeper technical level average score

Extensive Excel sheet for computing of all answers has been made and can be made available.

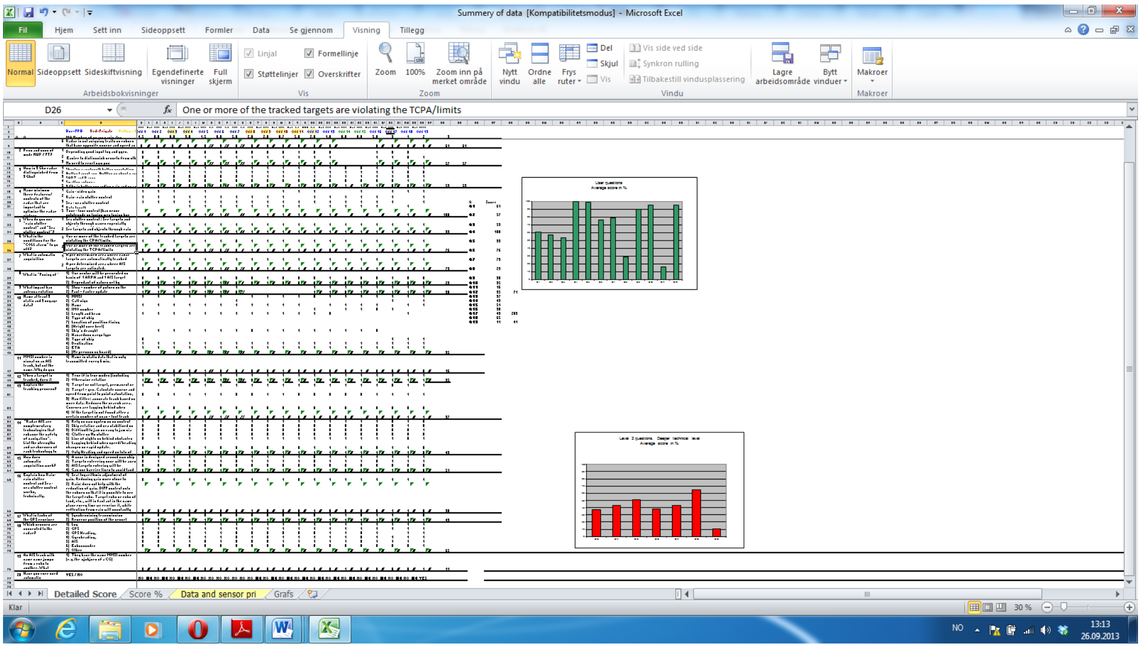


Figure 6.9 EXCEL sheet

Appendix D Royal Norwegian Navigation Centre Simulator Department

The Royal Norwegian Navigation Centre Simulator Department consist of:

- Four bridge simulators with a 210° visual image and a 30° aft visual image.
  - Set up with Kongsberg SM10 and DB10 system.
- One large bridge simulator with 360° visual image (intended use for Frigates).
  - Set up with 2x Kongsberg SM10 and DB10 system.
- One 1:1 Skjold-Class bridge simulator with a 210° visual image and a 30° aft visual image.
  - Set up with Kongsberg SM10 and DB10 system.

Design of the simulator is shown in figure below.

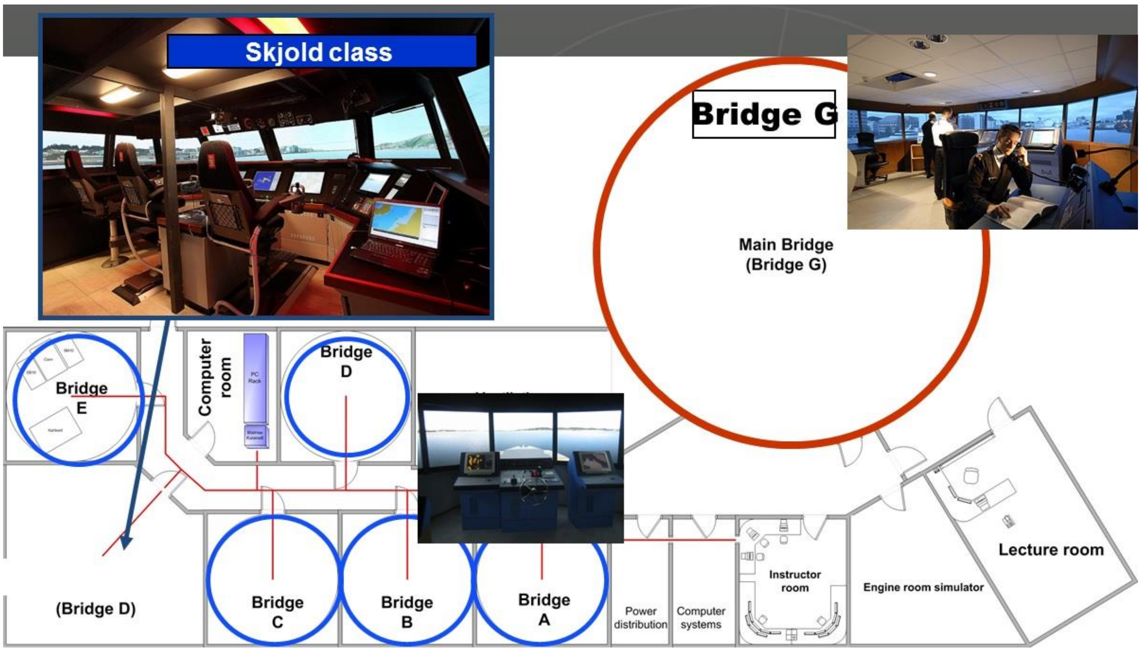


Figure 6.10 Design of simulator department at RNoNA.

Appendix E ECDIS Notation of Royal Norwegian Navy

This is made in Norwegian. Point being is that there are made abbreviations to fit into the message field in the ECDIS system so that the OOW knows which means he is to use to conduct safe navigation. The full notation list is found in the Royal Norwegian Naval Centre publication SNP 500 (NNC, 2012).

Hva (what)	Symbol, (symbol) forkortelse (abbr)	Merknad (note)
Tvers: (beam)	9	
45 grader relativt på baugen: (45 degrees relative on bow)	45	
Søyle, varde, båke: (pole, beacon)	S, V, B	
Stake, grønn/rød: (buoy, red/green)	RS, GS	
Kardinalmerke: (cardinal mark)	YB, YBY, BY, BYB	
Styrbord: (starboard)	sb	(alltid liten skrift) (always l. case letters)
Babord: (port)	bb	(alltid liten skrift) (always l. case letters)
Blink hvert tredje sek: (flash every third second)	W/3	
Varde: (beacon)	V	
Overett: (paralell)	>>	Objektene i overetten skilles med x (objects in parallell split by x)
Stevn lykt FM2: (head towards lighthouse occulting 2s)	>FM2	
Akterstevn lykt: (head away/aft heading lighthouse)	FM2<	
Passeringsavstand: (distance to object when passing)	(0.2)	merk parentes! (see brackets!)
Tvers til tørn/distanse fra oppdatering til passering: (distance from a beam to turn)	[0.7]	merk klamme! (see brackets)
Redusere farten: (reduce speed)	RED	
Luftspenn: (air cable)	LS	
Avstand i baug (radar): (distance in bow)	AB	
Parallellindeks (avstanden i parallellindeksen settes i parentes): (parallell index)	PI	
Videre informasjon i MESSAGE-feltet: (further info in message area)	(M)	

Table 6.3 Notation used in the Norwegian Navy

Appendix F Powerpoint presentation

The presentation is in Norwegian. If the reader would like an English version, please contact the author.

Workshop was conducted at Vestfold University College, Royal Norwegian Naval Academy and Aalesund University College.

Bakgrunn

* Sjøkrigsskolen nautikk
* Styrmann på MTB (Hauk- og Skjold-klasse)
  * 5 år
  * Siste stilling Nestkommanderende KNM Gnist
* Veileder navigasjon Sjøkrigsskolen
* Instruktør navigasjon

Bakgrunn for oppgaven

* Paradigmeskifte
* Tillit til ECDIS
  * Gårsdagens og fremtiden navigatører
* «Playstation mode»

* Krevende farvann og høy fart gir økt risiko.

* Kontroll av ECDIS = komplisert?

Forskningsmål

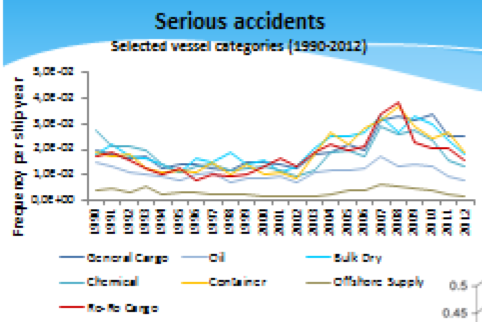
* Hvordan forbedre og utvikle kontroll av posisjonssensor valgt til ECDIS på et hurtiggående fartøy i innaskjærs farvann.

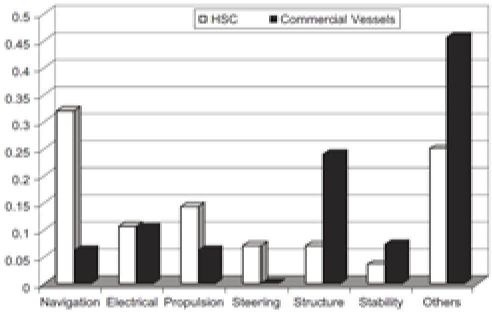
* *How to improve and develop the control of position input sensor chosen to ECDIS on a High Speed Craft in littoral waters.*

Gjennomføring

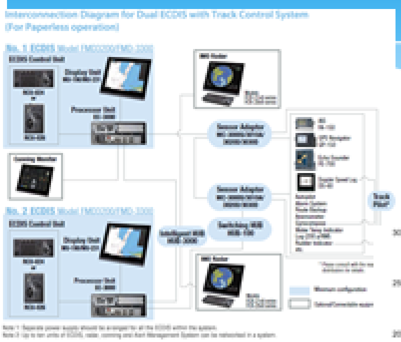
* Litteratursøk
* Seilas KNM Gnist (1 uke)
* Seilas NorLed (3 dager)
* Simulatortester
* Intervju navigatører
  * Kontrollmetoder
  * Systemkunnskap
* Intervju fagpersoner
  * Bakkenteigen
  * SKSK
  * HiALS
* Validering av funn

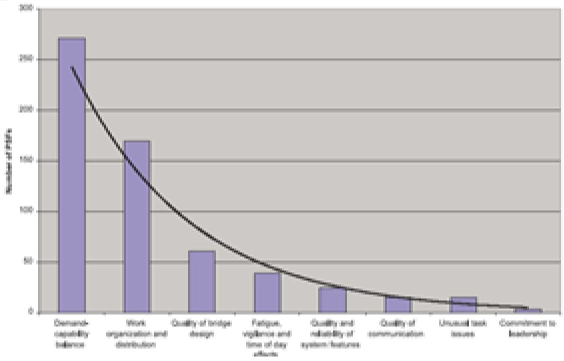
Litteratur





Litteratur

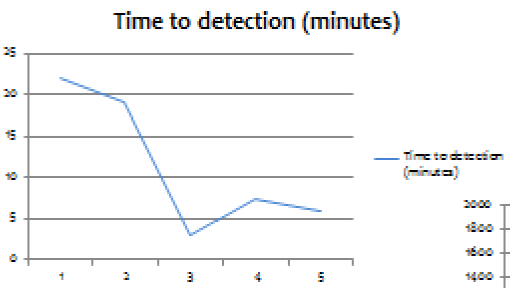


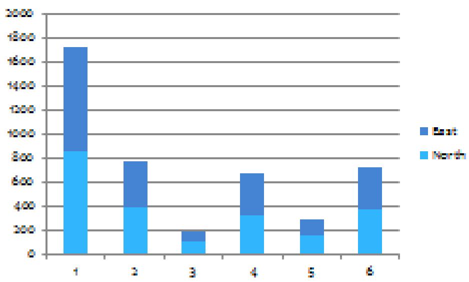


Seilas

- Militær vs sivil hurtigbåtnavigering
  - Områdekjennskap
  - Kontroll av ECDIS (prosedyrer)
- Trening
  - Simulatortilgang
- Forberedelser
  - Ruteplanlegging
- Gjennomføring av seilas
  - Bruk av hjelpemidler
  - Prosedyrer
  - Systemforståelse
    - Manualer (sammenfatning)

Simulatortester





Intervju

- Prosedyrer
  - Kontrollmetoder
- Manualer
  - Systemforståelse
- Trening
  - Nivåkontroll

Funn

- Prosedyrer og manualer
- Forberedelser!
  - Notasjon
- Riktig og målrettet trening
  - Nivåkontroll
- Systemforståelse
  - Hva forventes?
- Kontroll av ECDIS
  - Konvensjonell kontroll
  - Visuell kontroll

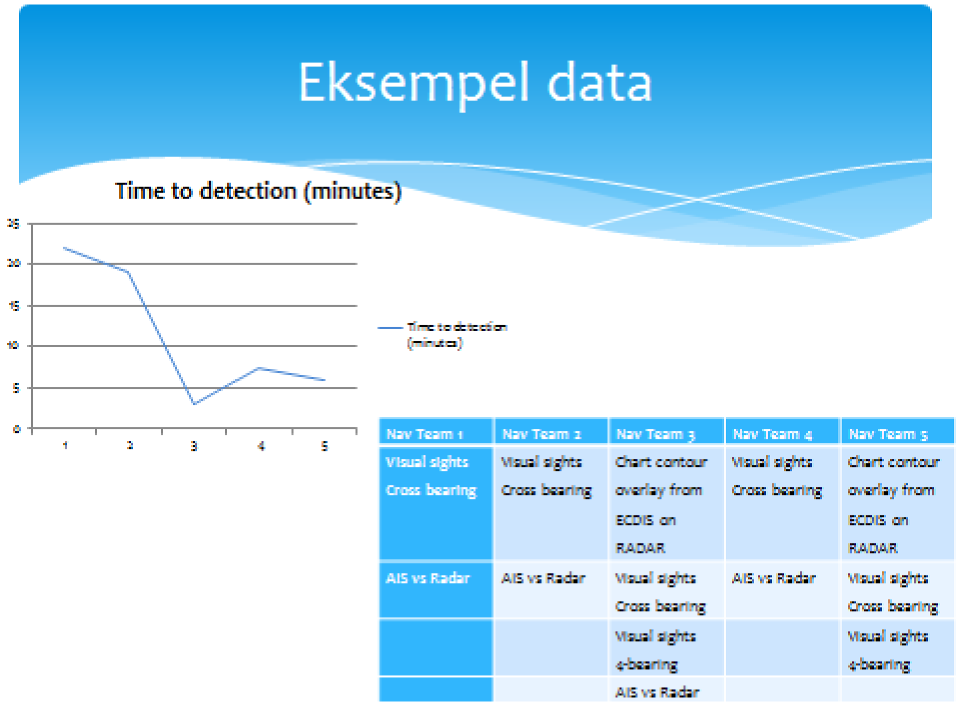


Figure 6.11 Powerpoint presentation

Appendix G Basic Maritime definitions and principles

Courtesy of Martin Hopland Bøhn (2011).

Use of heading point

This is the simplest navigational method. The key is to keep the same heading towards a known object. It may be a lighthouse, or a characteristic geographic point. If a ship heads against a fixed point with a constant fixed bearing to the point, it travels on a straight line. It may seem very easy, but the sea is constantly moving due to different currents. A ship is also affected by wind and waves.

Cross bearings

When bearings are obtained from two different objects at the same time, the ship's position must be at the point of intersection of the two lines of bearing (MoD 1987, p.208)

4-bearing

This principle is based on basic trigonometry saying that in a triangle with angles of 90° and double 45° the two sides on each side of the 90° angle are equal.

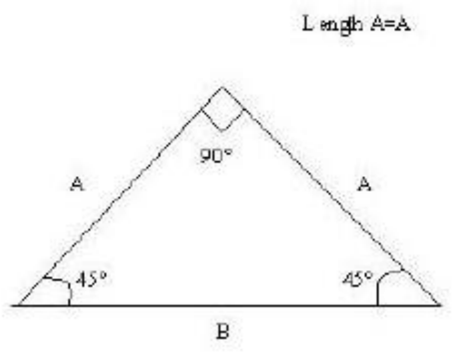


Figure 6.12 4- bearing principle

Using the stop watch or the trip log described above the navigator can measure the distance to a fixed point on shore by calculating the distance the ship is 64 travelling between having the fixed point in relative 45° to relative 90°.

Figure 6.13 4- bearing principle in map

½- bearing

This is also based on basic trigonometry saying that TAN 6° is almost equal to 0.1 (TAN 6°=0.1051). This principle is used in relative positioning of the ship. The key is 1/10.

$$Tan\ 6 = \frac{x}{1}$$

$$x = tan6$$

$$x = 0{,}105$$

$$x \sim 0{,}1$$

If a ship is approaching e.g. a lighthouse and the navigator wants to have a distance of 0.1NM to the lighthouse when passing it (relative 90°) he has to alter the course of the ship keeping 6° relative offset from the lighthouse 1NM before passing. This is best described by a picture.

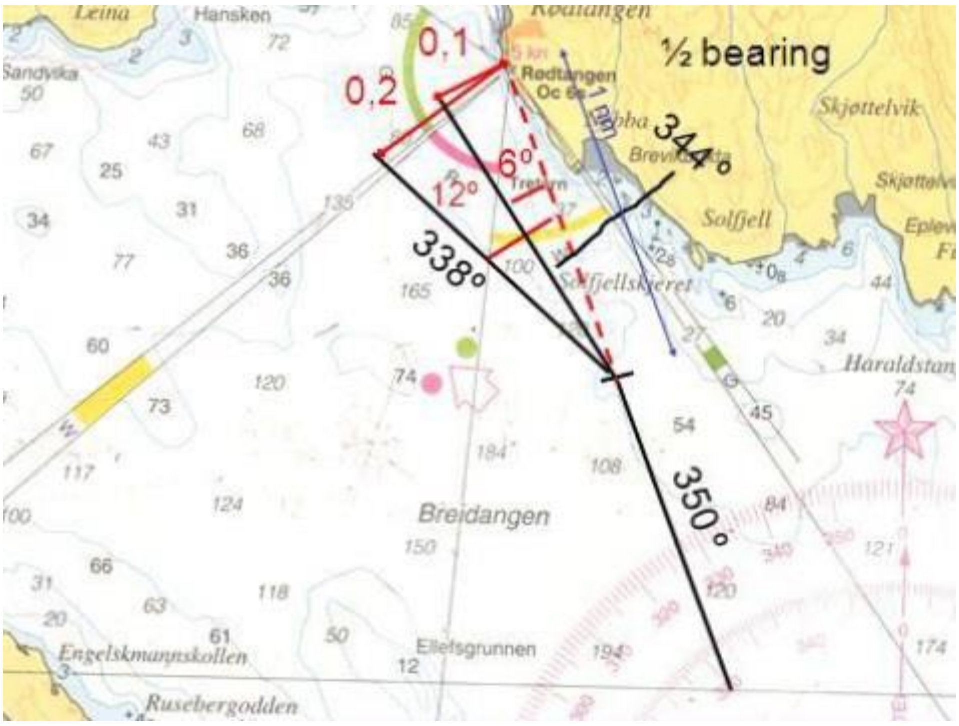


Figure 6.14 ½ bearing principle

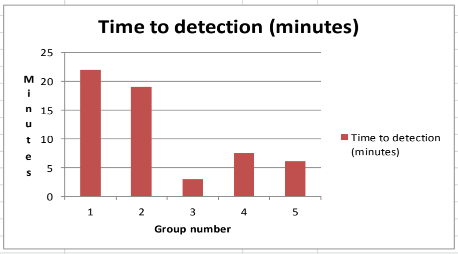
This principle is very much used in HSC navigation in the RNoN and is described several times in the interviews later in this thesis.

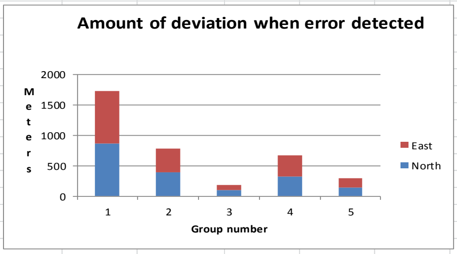
Use of aft heading point

Same principle as heading point but opposite way around. The ship sails away from a fixed geographic point trying to keep the same true bearing to the point.

Appendix H Simulator test statistics

Navigation team	Time to detection (minutes)			Navigation team	North (mete	East (meters)			
1	22			1	860	860			
2	19			2	390	390	301,380159		
3	3			3	100	90	269,562609		
4	7,5			4	330	340	301,380159		
5	6			5	150	140			
				Average	366	364	730	1830,0	1820
Average	11,5			Std avvik pop	269,562609	272,9542086	271,258409		
Std avvik pop	7,549834435								





	110,25							
	56,25		Mean values time to detection:		Mean values amount of drift:			
	72,25		3,950165565		96,4373913	91,04579139		458,7
	16		19,04983444		635,562609	636,9542086		1001,3
	30,25							
stdav	7,549834435							

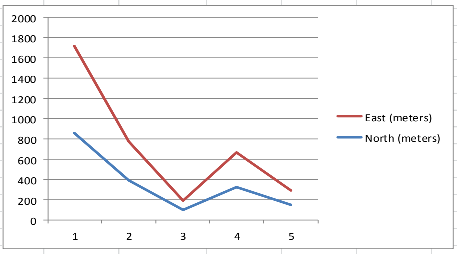


Figure 6.15 EXCEL sheet simulator test statistics