Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Engineering Cybernetics

Sara Emilie Thode

Shared Situation Awareness in Maritime Navigation

Master's thesis in Cybernetics and Robotics
Supervisor: Thor Hukkelås and Øystein Andreassen
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Preface

This thesis is written for the course ’TTK4900 - Engineering Cybernetics, Master’s Thesis’. The thesis presents the results of the work done in a period of 20 weeks. The work with the thesis was carried out at the Department of Engineering Cybernetics at the Norwegian University of Science and Technology (NTNU).

First, I would like to thank Sivilingeniør Thor Hukkelås for inspiring me to learn more about and seeing the importance of Situation Awareness in cybernetic systems through the subject *TTK30 - Human-Machine/autonomy interaction in cyber-physical systems*. Without the inspiring lectures, I would not have discovered this interest of mine. I would like to extend my sincere gratitude to my supervisors, Sivilingeniør Thor Hukkelås and Sivilingeniør Øystein Andreassen, for their guidance and expertise, which have been invaluable, and their admirable enthusiasm. I would also like to thank Charlotte Skourup PhD for the literature and conversations about Situation Awareness.

Secondly, I would like to thank my boyfriend for the hours spent on proofreading and discussing the thesis and for tolerating and supporting me during stressful times during my master.

Last but not least, I would like to thank my friends and family for all their support and loving words over the past couple of years and the lunch group for making every day funnier with endless hours of laughs.

Abstract

The thesis aims to identify the elements of Shared Situation Awareness (Shared SA) for the final purpose of examining the change in Shared SA when autonomous ships and Remote Operation Centers (ROC) enter the maritime environment.

Shared SA is essential in navigation and must be supported in the future maritime environment. The Shared SA is mainly supported through verbal and visual information sharing. However, new problems arise when autonomous ships are introduced. Autonomous ships cannot handle verbal communication, and seafarers must trust the autonomous ships.

To address the issue of maintaining Shared SA, a theoretical foundation revolving around situation awareness is created. Based on the theoretical foundation and literature describing different aspects of the maritime environment, information matrices containing the information needed by maritime participants to obtain Shared SA are created, and the technology used to share the information is identified.

The results show that Shared SA will become even more critical when introducing autonomous ships. New information is required, and the information needs increase. The combination of existing and new technology covers most of the information needed in the future maritime environment to acquire Shared SA. However, there still exists a need for future technology which can close the potential technology gap.

Future research should focus on the information and new technology needed to support all the maritime participants' Shared SA. Furthermore, rules and regulations regarding autonomous ships and remote operation centers should be established.

Sammendrag

Hensikten med oppgaven er å identifisere elementene i Shared Situation Awareness (Shared SA) for å undersøke endringen i Shared SA når autonome skip og fjernoperasjonssentraler (ROC) inkluderes i det maritime miljøet.

Shared SA er essensielt i navigasjon og må støttes i det fremtidige maritime miljøet. Shared SA støttes hovedsakelig gjennom verbal og visuell informasjonsdeling. Nye dilemmaer oppstår imidlertid når autonome skip introduseres. Autonome skip kan ikke håndtere verbal kommunikasjon, og det må skapes tillit til autonome skip.

For å adressere problemet med å opprettholde Shared SA, ble det dannet et teoretisk grunnlag om Situation Awareness. Basert på det teorien og litteratur som beskriver ulike aspekter ved det maritime miljøet, ble det laget informasjonsmatriser som inneholder informasjonen som maritime deltakerne trenger fro å opprettholde Shared SA, og teknologien som brukes for å dele informasjonen ble identifisert.

Resultatene viser at Shared SA vil bli enda mer viktig ved introduksjon av autonome skip. Det kreves ny informasjon, og dermed øker informasjonsbehovet. Kombinasjonen av eksisterende og ny teknologi dekker det meste av informasjonen som trengs i det fremtidige maritime miljøet for å danne Shared SA. Imidlertid eksisterer det fortsatt et behov for fremtidig teknologi som kan lukke det potensielle teknologigapet.

Fremtidig forskning bør sette søkelys på informasjonen og ny teknologi som trengs for å støtte alle de maritime deltakernes Shared SA. Videre bør lover og regler vedrørende autonome skip og fjernoperasjonssentraler etableres.

Contents

Figures

Tables

Acronyms

AIBN Accident Investigation Board Norway. 27

AIS Automatic Identification System. 9, 27, 28, 39, 40, 43, 44, 47, 50, 56, 61, 63, 64, 74

ARPA Automatic Radar Plotting Aid. 56, 60, 63

ASRS Aviation Safety Reporting System. 19, 21

BRM Bridge Resource Management. 28

COLREG Convention on the International Regulations for Preventing Collisions at Sea. 10, 43, 50, 52, 57, 71, 72, 74

Distributed SA Distributed Situation Awareness. 23, 29, 31, 34

ECDIS Electronic Chart Display and Information. 56, 59, 60, 62, 63, 66, 68, 71, 72

EMSA European Maritime Safety Agency. 1

ENC Electronic Navigational Chart. xiii, 56, 59, 62, 63, 68, 72

ETA Estimated Time of Arrival. 51, 61, 64, 68, 72

ETD Estimated Time of Departure. 51, 61, 64, 68, 72

GDTA Goal-Directed Task Analysis. xiii, 35–40, 49, 78, 79, 84

GHG Greenhouse Gases. 1

GLONASS Global Navigation Satellite System. 56, 60

GPS Global Positioning System. 56, 60, 63

HF Human Factor. 17, 42

IMO International Maritime Organization. 7–10, 40, 44, 53, 62, 71

INS Information Service. 44

IP Information Pack. 46, 47, 49–54, 62–64, 69–75

MUNIN Maritime Unmanned Navigation through Intelligence in Networks. xiii, 1, 5, 7, 42, 45, 66, 69, 70

NAS Navigation Assistance Service. 44

NAVTEX Navigational Telex. 61, 64

NCA Norwegian Coastal Administration. 44, 53, 62

NFAS Norwegian Forum for Autonomous Ships. 5, 45

NMA Norwegian Maritime Authority. 6

OCT On-board Control Team. 5, 6, 50–53

OODA-loop Observe, Orient, Decide, Act loop. 31, 32

OOW Officer of the Watch. 28, 38, 39

OTL Out-of-The-Loop. 35, 69

QGILD Quickly-getting-into-the-loop. 66, 67, 69

RADAR Radio Detection and Ranging. 30

RCC Remote Control Center. 8

RCDS Raster Chart Display System. 56, 59, 63

ROC Remote Operation Center. xiii, xv, 1–3, 6–8, 34, 37, 38, 41–45, 49–55, 65–72, 74, 75, 79–81, 83, 84

SA Situation Awareness. xiii, xxi, 2, 3, 8, 10, 11, 13, 17–27, 29, 31–35, 41, 42, 45, 48, 56–58, 63, 65, 67, 77, 83, 84

SADA loop Situation Awareness, Decision, Action loop. xiii, 32, 33

SAIBN Defence Accident Investigation Board Norway. 27

SAR Search and Rescue. 25, 29

SCC Shore Control Center. 8

Shared SA Shared Situation Awareness. xiii, xv, 2, 3, 5, 11, 13, 23, 25–31, 34, 35, 37, 41, 44, 45, 48–50, 52, 53, 55–59, 62–67, 69–72, 74, 77, 79–81, 83, 84

SMEs Subject Matter Experts. 36, 38, 49

SOLAS International Convention for the Safety of Life at Sea. 10

SSN Safe Sea Net. 61, 64, 68, 71, 72

Team SA Team Situation Awareness. 23–25, 29, 31

TOS Traffic Organization. 44

TSS Traffic Separation Scheme. 59, 62, 63

UN United Nations. 1, 10

VHF Very High Frequency. 13, 43, 46, 49, 51, 56, 62–64, 71, 75

VTS Vessel Traffic Service. xiii, xv, 2, 3, 9, 10, 21, 29, 34, 37, 38, 43–47, 49–53, 55, 62–65, 71, 72, 74, 75, 79, 80, 83, 84

Glossary

Chief Mate or Chief Officer has the ultimate responsibility for handling cargo and efficiently running the ship [1, 2]. 19

confirmation bias the tendency to process information by looking for, or interpreting, information that is consistent with one's existing beliefs[3]. 29

element The things an operator need to perceive and understand the environment [4]. 18–21, 24, 28

HNoMS Helge Ingstad His/Her Norwegian Majesty's Ship Helge Ingstad was a Norwegian Fridtjof Nansen-class frigate owned by the Norwegian State Ministry of Defence [5]. xv, 13, 27, 28, 38–41, 44, 46, 49, 53, 81

IP A package containing multiple Shared SA requirements. 46–48, 53, 54, 66, 72, 75, 95–99, 101

SA requirement the dynamic information which is needed to perform a given work [6]. xiii, xv, 20, 21, 23–26, 29, 35–45, 48, 50, 51, 56, 64, 65, 71, 79, 80, 83, 95–99

Second Mate or Second Officer are responsible for the navigation of the ship, and are seen as the safety officer [2]. 20

Shared SA requirement the information form all SA levels that is shared between team members [6, 7]. xv, 25, 30, 38, 43–55, 57, 63–66, 70, 72–75, 77–81, 83, 84, 95–98, 101

situation assessment All processes needed to achieve, acquire or maintain the situation awareness [4]. 18, 19, 24, 30, 45, 55, 56, 63, 65

situation awareness A state of knowledge in a situation, from the processes used to achieve that state. [4]. 18

Sola TS A double hull tanker for carrying crude oil operated by Tsakos Columbia Shipsmanagement (TCM) [5]. 13, 27, 28, 38

Three Level Model model of how to obtain situation awareness, with the three levels *perception, Comprehension* and *projection* [4]. xv, 18, 21–23, 25, 26, 32–34, 39, 55

Chapter 1

Introduction

1.1 Background

The United Nations (UN) has defined the 17 Sustainability Development Goals to create a better and more sustainable future. Goal 13 regards climate change and the urge for preventive measures to tackle climate change. The Paris Agreement was adopted in 2016 to work towards limiting the global temperature rise to below 2 °C, and strive towards no more than 1.5 °C [8]. One of the measures is to reduce the Greenhouse Gases (GHG).

80 % of all global trading, by volume, is transported with shipping, and is the most environmentally friendly and energy-efficient transport mode [9, 10]. In 2018, the shipping industry accounted for approximately 2,9 % of the global CO_2 emissions [11]. According to an analysis performed by DNV GL, Norway can reduce their emissions for transportation between mid-Norway and Europe by 50 % just by moving the transportation from land to sea based[12]. The example from Norway indicates that the need for shipping will maintain if not increase.

As the need for shipping will maintain or increase, so will the number of ships operating in the maritime environment. The risk of unwanted situations rises when additional ships are entering the environment. Between 2014-2020 the European Maritime Safety Agency (EMSA) reported on average 2 712 accidents and incidents each year, where on average 77 of them each year was classified as *Serious marine casualty* or *Very serious marine casualty* [13].

Due to environmental, safety, and also economic reasons, functions regarding the domain of autonomous ships and ROC are rapidly developing [14]. The UN project Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) was the first large-scale study of autonomous ships, which went on from 2012 to 2015 [15]. DNV GL [14] stated, "The main challenge for implementing fully automated systems controlled by remote operators or by algorithms is not to make them work, but to make them sufficiently safe.".

Both autonomous and manned ships will operate in the future maritime environment. Even though the autonomous ships will eliminate some situations where human errors can occur, human error can still arise concerning ROC and manned ships. 757 investigation reports of marine causalities were written between 2014 to 2020, from which 2 011 safety recommendations were formed. Of these safety recommendations, 20 % were related to human factors. To minimize the risk of human errors, the different participants must possess an adequate Situation Awareness (SA), and as the participants operate in the same environment, Shared Situation Awareness (Shared SA) becomes crucial.

1.2 Objective and purpose

The participants' information must be identified to design technology for the future maritime environment with autonomous ships and ROC. Analyses of the elements needed to gain SA for the navigational crew on manned ships have been performed. Still, in the future maritime environment with autonomous ships and ROC the elements might change [16].

The purpose of the thesis is to review and present different theories of SA and Shared SA, and investigate the importance of Shared SA in the future maritime environment, which includes autonomous ships and ROC. Through answering the research questions presented below, the importance of Shared SA can be investigated.

- What are the definitions of and what affects Situation Awareness (SA) and Shared Situation Awareness (Shared SA)?
- Which elements are needed for manned ships, autonomous ships, recreational crafts, Remote Operation Center (ROC) and Vessel Traffic Service (VTS) to gain Shared SA?
- Which technology is used to maintain and acquire the Shared SA between manned ships, recreational crafts and Vessel Traffic Service (VTS) in the present maritime environment?
- Which technology can/should be used to maintain and acquire the Shared SA between manned ships, autonomous ships, recreational crafts, Remote Operation Center (ROC) and Vessel Traffic Service (VTS) in the future maritime environment?

1.3 Limitations

The research methods are based upon knowledge gained through literature reviews. Achieving a theoretical and practical understanding of situations occurring in the maritime environment would be desirable, but due to time limitations, there were not performed any interviews or surveys.

To gain an in-depth understanding of the elements and the technology used to support the Shared SA the number of participants had to be limited. The chosen participants are the ones who, under normal circumstances, are closely collaborating regarding navigation.

Emergency situations are considered highly complex, and the information needs change significantly compared to normal circumstances. Therefore, emergency situations are not considered in this thesis.

1.4 Outline

Chapter 2 defines the maritime environment with the various participants operating in it. Definitions of the different participants will be stated and used as a basis throughout the thesis.

Chapter 3 outlines the procedure and strategy used in the multiple literature reviews. Databases, search words, and the selection of literature will be described.

Chapter 4 defines and discusses various theories of Situation Awareness (SA) and Shared Situation Awareness (Shared SA), and their connection to decision-making. The theory presented will be used as the theoretical basis for the thesis.

Chapter 5 identifies and discusses the elements needed for manned ships, autonomous ships, recreational crafts, ROC and VTS to gain and maintain a Shared SA. The elements will be structured in information matrices which will describe each participant's information needs from the other participants in different voyage phases.

Chapters 6 and 7 presents and discusses existing and future technology which can be used to maintain and acquire the Shared SA between the participants. Lists of existing and future technology will be presented. Their ability to support Shared SA will be measured against the list of elements identified in Chapter 5, and be discussed.

Chapter 2

Background

The objective of the following chapter is to provide the reader with an understanding of the maritime environment and the participants working in it. The knowledge is vital to understanding the complexity of Shared Situation Awareness (Shared SA) in maritime operations.

2.1 Maritime Environment

As presented in Chapter 1 more than 80 % of the global trade is transported by sea. The vessel will operate in various environments, varying from internal waters as restricted and coastal waters to the high seas (international waters) [17]. In the different environments, the navigational hazards differ. There could be reefs, rocks, shoals, or high traffic density in coastal waters. The internal waters can also include container and feeder ports, terminals, and quays. On the other hand, on the high seas, the navigational hazards can be storms, rough seas, and darkness [18–21].

Both the MUNIN project and NFAS has defined the autonomous voyage in different phases [22, 23]. Throughout the different voyage phases, the control and manning of the autonomous ship vary. Figure 2.1 presents the different phases, where the definition of the phases are presented in the bullet points below. The naming and definition of the voyage phases used in the thesis are inspired by both Rødseth et al. [22] and Rødseth and Nordhal [23].

- *Berth:* At berth, the ship is unloaded and loaded. Further, the voyage route is planned with multiple waypoints.
- *Port:* The ship is manually controlled from the bridge by a pilot and Onboard Control Team (OCT) as the environment in the port phase can consist of dense traffic, shallow waters, and there can be areas where there is restricted maneuverability.

- *Approach:* The ship is manually controlled from the bridge by OCT, but can be assisted by the Remote Operation Center (ROC). In the approach phase, the environment can vary from dense traffic and shallow waters to a few ships and open waters.
- *Transit:* The ship sails in 'autonomous mode' and the control can vary between *Autonomous control*, *Indirect Remote Control* and *Direct Remote Control* which will be described in Section 2.1.2. This phase is in open and unhindered seas, where there are few ships around.

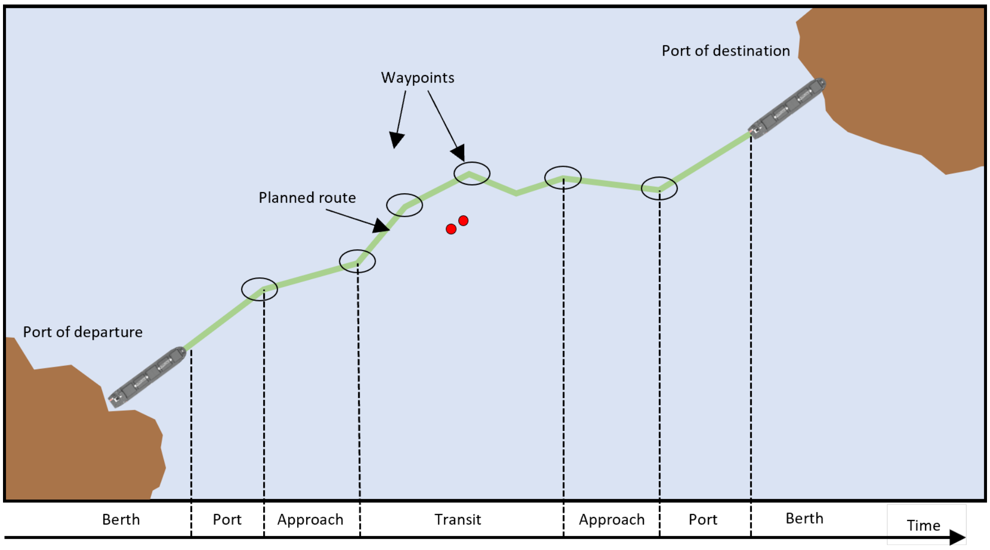


Figure 2.1: The voyage phases for an autonomous ship. Adopted from Thor Hukkelås, Rødseth and Nordhal [23] and Rødseth et al. [22].

Figure 2.1 presents the different voyage phases. The information need for the participants' changes in the different phases and maritime environments. In order to understand the information need, the participants evaluated in this thesis are defined in the following sections.

2.1.1 Manned ships

The Norwegian Maritime Authority (NMA) acknowledges five groups of vessels; passenger vessels, cargo vessels, mobile offshore units, fishing vessels and recreational crafts [24]. Some of the groups can be divided into subgroups according to their cargo or operation, i.e. bulk carriers, container ships, tankers, ferries and cruise ship [25]. This thesis defines manned ships as passenger, fish, or cargo vessels. In other words mobile offshore units and recreational crafts are not included in the term *Manned Ships*.

2.1.2 Autonomous ships

Autonomous ships are evolving fast. On April 29th 2022, Yara Birkeland was inducted into operation as the world's first electric and autonomous container ship, and many projects such as AUTOSHIP and ASKO are on their way [26–29]. It is not yet defined rules specific for autonomous ships. In the *'Transport 2040'* report presented by the World Maritime University, it is written that DNV GL in 2018 thought it would be optimistic to assume that international regulations for autonomous ships will be in place before 2035 [30, p. 6]. Even though there are no rules in place, International Maritime Organization (IMO) has defined four levels of autonomy which are presented in Table 2.1.

Table 2.1: Degree of autonomy defined and adopted from International Maritime Organization [31].

Degree	Description
One	*Ship with automated processes and decision support:* Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
Two	*Remotely controlled ship with seafarers on board:* The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
Three	*Remotely controlled ship without seafarers on board:* The ship is controlled and operated from another location. There are no seafarers on board.
Four	*Fully autonomous ship:* The operating system of the ship is able to make decisions and determine actions by itself.

The degree of autonomy is related to the voyage phases. The second degree relates to the port and approach phase, where the autonomous ship is manned. In the transit phase, the control mode for the autonomous ship can vary between *Autonomous control*, *Indirect Remote Control* and *Direct Remote Control*. MUNIN defines *Indirect Remote Control* as the ROC operators only interfering with the system with plan updates. *Direct Remote Control* is when the ROC operator has taken overall control of the ship, meaning they correspond to the third degree of autonomy. On the other hand, *Autonomous control* relates to degree four of autonomy as the ship is only monitored by the ROC operators [22].

2.1.3 Remote Operation Center

Remote Operation Center (ROC) is a new participant in the maritime environment, along with the autonomous ships. For the four degrees of autonomy by IMO displayed in Table 2.1 degrees 2-4 need someone to control or monitor the ship remotely. The monitoring or remote control can be performed from a ROC, also called a Shore Control Center (SCC) or Remote Control Center (RCC) [32–34]. The different terms vary according to where the remote center is situated and which tasks the operators will perform. As ROC does not specify if the remote center is onshore or offshore, nor its limits of the tasks performed in the center, it is used in this thesis.

As the ROC might need to control the autonomous ship remotely for various reasons, the operator must possess an SA which gives the operator a firm basis for making correct decisions. In order to acquire a satisfactory SA the operator must interact with the different participants shown in Figure 2.2 [32].

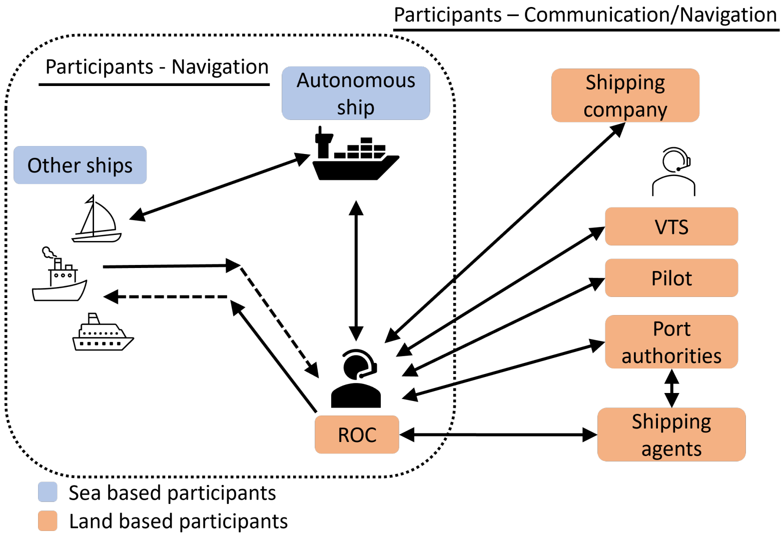


Figure 2.2: Illustration of the participants the Remote Operation Center (ROC) must interact with. The participants are divided by whom is directly operating in the maritime environment and whom is used for navigation assistance or other services. The blue participants are sea based, while the orange ones are land based. Adopted from MacKinnon et al. [33].

2.1.4 Recreational crafts

A recreational craft is defined in the Directive 2013/53/EU [17] as "...any watercraft of any type, excluding personal watercraft, intended for sports and leisure purposes of hull length from 2,5 m to 24 m, regardless of the means of propulsion...".

Recreational crafts are defined as individual participants as they do not apply the same rules as a passenger, fishing, and cargo vessels. For instance, while cargo vessels are required to carry Class A Automatic Identification System (AIS), recreational crafts are not required to carry an AIS system even though it exists an optional Class B AIS for recreational crafts. Class B AIS transmits less information at a lower frequency than Class A [35, 36].

2.1.5 Vessel Traffic Service

The Vessel Traffic Service (VTS) is an international standardized risk-reducing service created to protect the environment and improve the safety and efficiency of vessel traffic. IMO has defined guidelines for VTS that includes the VTS operating in designated areas defined as VTS areas. The VTS operates as an information service but can also provide navigational assistance services and traffic organization services. Their responsibility can vary from giving clearance to enter the VTS area and organizing maritime traffic to be a front-line emergency response to acute pollution. Through their tasks, the VTS operators are in contact with all the different participants presented in this Chapter [5, 37, 38].

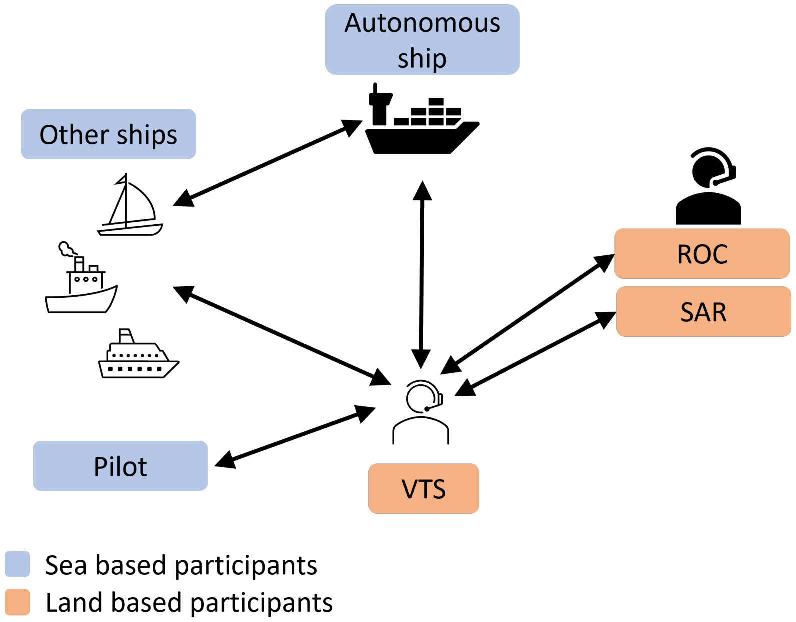


Figure 2.3: The participants which communicates with VTS. The blue participants are sea based, while the orange ones are land based. Inspired by MacKinnon et al. [33].

Figure 2.3 displays the different participants the VTS must communicate with. The VTS interacts with the different participants to form a satisfactory SA for themselves and the participants and reduce the risk of collisions. In this thesis, the VTS is defined as providing informational, navigational and traffic organizational services, even though this can vary from countries and areas [39].

2.1.6 International Maritime Organization

The International Maritime Organization (IMO) is a UN organization. Their main responsibility is to ensure the safety and security of international shipping and prevent pollution by ships [40]. IMO drafts conventions, agreements, and other related tools related to shipping, and they encourage governments to adopt the conventions and agreements and offer consultation in the exchange of information between members and governments. Different conventions and guidelines formed by IMO will be used in the project, i.e Convention on the International Regulations for Preventing Collisions at Sea (COLREG) and the International Convention for the Safety of Life at Sea (SOLAS).

Chapter 3

Literature review

Four literature reviews were performed to gather research about Situation Awareness (SA) in maritime operation to answer the research questions presented in Section 1.2. The intention was to examine and compare the different perspectives on SA and Shared SA in the research community and what kind of information participants in maritime operations need to acquire a satisfactory SA. Further, the presentation of the information in the present and the future maritime environment was also examined. The finding are thoroughly analyzed, presented directly in Chapter 4, and used as a theoretical basis for Chapters 5 to 7.

3.1 Strategy used in the literature review

The following section will describe the method used to search, identify, evaluate and structure the literature. Search engines and search words used in the literature review will be presented, and the identification and structuring of relevant literature will be specified in the following section.

3.1.1 Search engines, search words and snowballing

In order to identify relevant literature based on the research questions and information need, methods were created to ensure literature from both wide and narrow searches.

Search engines

There exist multiple academic search engines and databases for obtaining relevant research literature. Table 3.1 presents the databases and search engines used to obtain relevant literature for this thesis and literature review.

Table 3.1: Search engines and databases used in the literature review.

Search engine	Database
Google Scholar	The database includes academic articles within all research fields and languages, and from all countries and time periods [41]. It is especially useful for wide searches.
Oria	A database which combines all sources from most Norwegian study specific and research libraries. Boolean operations can easily be implemented in a search. [42]
ScienceDirect	An Elsevier database for peer-reviewed journal articles and book chapters [43]. Related books or articles are easily displayed.

Search strategy and search words

Based on the research questions presented in Section 1.2 specific search words were defined. The search words were found to produce an adequate selection of relevant literature. Throughout the literature review, the search words changed in relation to the different subjects, and as the search got more narrow and specific. The search words were mainly in English, but Norwegian search words were also used when the searches were related to Norwegian authorities and regulations.

The search words were used separately or together with the Boolean 'AND' operation, as shown in Table 3.2. Other Boolean operations such as 'OR' and 'NOT' can also be used in searches with multiple search words. The Boolean operations were used to narrow the searches. In Table 3.2, it can be seen that the search for 'Situation Awareness' in Oria resulted in 2 832 sources, while 'Situation Awareness' AND 'maritime' resulted in only 215 sources.

Table 3.2: Search results in different databases for some of the search words used in the four literature reviews.

Search word	Database	Number of results
’Situation awareness’ in Title	Google Scholar	6 320
’Situation Awareness’ in Title	ScienceDirect	452
’Situation Awareness’ in Title	Oria	2 832
’Situation Awareness’ AND ’maritime’	Oria	215
’Shared Situation Awareness’ in Title	Google Scholar	110
’Shared Situation Awareness’ in Title	Oria	51
’Remote Opeartion Center’	Oria	78
’Remote Operation Center’ AND ’maritime’	Oria	4
’Shore Control Center’ AND ’unmanned ship’	Google Scholar	989

Snowballing

The search strategy Snowballing can be defined as using the reference list or the citations of a paper to discover new papers. The use of citations in a paper is referred to as forward Snowballing. In contrast, Backward snowballing is defined as "... using the reference list to identify new papers to include ..." by Wohlin [44].

Backward Snowballing is used to discover more relevant literature through the reference list of another paper. According to Wohlin [44] the papers on the reference list which do not fulfill different criteria, i.e., language or type of paper, should be disregarded. Further, after the first selection of papers is found, the examined papers are excluded. Lastly, Wohlin [44] describes the process of examining the identified papers according to the title, publication venue, and author etc.

Backward Snowballing was used in the literature review. It was used to find new information about the different subjects and verify the already identified papers by identifying literature with corresponding results.

Recommended literature

The thesis supervisors Thor Hukkelås and Øystein Andreassen recommended relevant papers, theses, videos, digital lectures, and conferences. A digital conference by Endsley [45] and a video describing the accident between HNoMS Helge Ingstad and Sola TS with Very High Frequency (VHF) and RADAR recordings were suggested to get an overview of SA and the consequences of acquiring an incomplete Shared Situation Awareness (Shared SA). Further, the book *Designing for Situation Awareness* by Endsley [6] and multiple articles were recommended throughout the semester. In addition, Charlotte Skourup, the Department manager for Product Lifecycle at ABB, recommended the paper *Toward a Theory of Situation Awareness in Dynamic Systems* by Endsley [4] and more.

3.1.2 Evaluation and selecting strategy for literature

A strategy for the selection of the relevant literature was formed. The method is based on own experiences, courses in source criticism, and recommendations from supervisors. Figure 3.1 presents the chosen strategy.

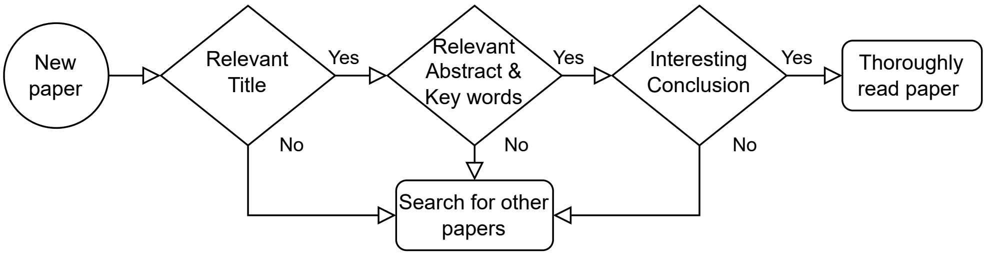


Figure 3.1: Flow chart for evaluation and selection literature.

After identifying new literature, i.e., a paper, the title is evaluated for its relevance to the information need and research questions. After that, the aim of the research presented in the abstract was evaluated. Literature that passed the first two steps was inserted into Mendeley, which is more thoroughly described in Section 3.1.3.

Lastly, the conclusion was evaluated. When evaluating the conclusion, the questions asked were *'did the author perform the intended tests?', 'Are the results interesting for the research questions?'* and *'did the author disprove some theories or hypothesis?'*. If the literature passed the three steps presented in Figure 3.1 it was read thoroughly, but if the literature did not pass the steps, it was disregarded, and new literature was searched for.

It is important to use sources that are quality assured to ensure a project's quality. In order to quality assure the literature which passed the three steps in Figure 3.1, there were established specific criteria the literature had to fulfill. The criteria are based on the T-O-N-E principal, Troverdighet (Reliability), Objektivitiet (Objectivity), Nøyaktighet (Accuracy), and Egnethet (Aptitude) presented by NTNU [46]. The bullet points present some of the questions asked when evaluating identified literature. All literature that was selected through the process shown in Figure 3.1 was evaluated with the presented criteria.

- Reliability - Where is the literature published?
- Objectivity - Is the author presenting more than one angle, and does the author try to convince or inform the reader?
- Accuracy - Is the research process explained in detail, and can the results be verified in at least two other sources?
- Aptitude - Are the results relevant to the research questions?

3.1.3 Managing and use of evaluated literature

After the literature was identified, selected, and evaluated, the literature was managed in Mendeley. Mendeley is a reference manager who also generates references for LaTeX.

The literature classified as acceptable was used in the project. A LaTeX-template by NTNU was used to structure the thesis, whereby the chapters, sections, and subsections were defined after that. For each section, relevant literature was read, analyzed, and presented. The method was used throughout all the sections in Chapter 4. In Chapters 5 to 7 the method was even more extensive in order to produce the best results.

Chapter 4

Theoretical background

4.1 Situation Awareness

Endsley [6] describes Situation Awareness (SA) as being aware of what is happening around you, and understanding what that information means to you now and in the future. The first known discussion of SA was during World War I in the military aviation community [47, 48]. Despite the term being discussed already in the early 1900s, it was not concidered in scientific research before the mid 1980s by the aviation and air traffic control field [45, 47]. In 2005 Lee et al. [49] found that four out of the ten most cited papers published between 1990-1995 were research on Situation Awareness [49, 50]. The findings of Lee et al. show that there was significant research interests on SA throughout the 80s and 90s. All the different research and usage of the SA term resulted in SA being categorized and described as "*the buzzword of the 90s*", "*ubiquitous phrase*" and "*victim of rather loose usage*" in the 90s. However, the term is now firmly established within the Human Factor (HF) and ergonomics fora [4, 51, 52].

As the research interest increased, the HF community began to study the possibility for SA to be valuable in other domains [47]. The theory and concept is now studied in a wide area of research domains like the military (Penney et al. [53]), energy distribution (Panteli and Kirschen [54]), transportation (Zhu [55]), autonomous ships (Zhou et al. [56]), medicine and health care (Wright and Endsley [57] and O'Meara et al. [58]), process plants (Naderpour et al. [59]), and sports (Di tore et al. [60]), among others.

4.1.1 Definitions of Situation Awareness

SA is a concept which usually is applied in operational situations, where both the goals and the objectives of the operational situation drives the information seeking [6, 45]. Through the years there have been presented numerous definitions of SA. Salmon et al. [47] performed a literary review on different SA definitions, and identified over 30 different definitions. The discussion is often based upon if SA is the process of gaining awareness or the product of awareness, or a combination of the two, and which methods should be used to measure SA [47, 50].

Smith and Hancock [61] (1995) defined SA as "adaptive, externally directed consciousness" or in other words as "the invariant in the agent-environment system that generates the momentary knowledge and behavior required to attain the goals specified by an arbiter of performance in the environment." [47, 61]. Sarter and Woods [52] (1991) defined SA as "all knowledge that is accessible and can be integrated into a coherent picture, when required, to assess and cope with a situation" [52]. The most commonly used definition is formulated by Endsley [4, p. 36]

> ‘The *perception* of the elements in the environment within a volume of time and space, the *comprehension* of their meaning, and the *projection* of their status in the near future.’

Endsley [4] defined situation awareness as the product of awareness, and defines the process of gaining awareness as situation assessment. According to Salmon et al. [47] the definition by Endsley [4] is the most cited, and as a result, this thesis will be based upon Mica Endsley*'s* Three Level Model [4].

4.2 The Three Level Model

As presented in Section 4.1 SA can be used in a variety of domains, and it exists different definitions of the term, meaning that the elements of SA varies along with the different domains [6]. The definition by Endsley shown in the Quote, called the *Three Level Model*, and includes the three levels below. The levels displayed below are not linear stages but ascending levels of SA. In other words, the three levels can be updated independently of each other [50]. The different levels are described in more detail in Sections 4.2.1 to 4.2.3.

- Level 1 - Perception of the elements in the environment
- Level 2 - Comprehension of the current situation
- Level 3 - Projection of future states

SA and the Three Level Model can be seen as a stage in the decision-making process, where the SA is affected by different factors, i.e., goals and objectives, stressors, interfaces, and more. Figure 4.1 visualizes both the internal and external factors which can affect the SA. It also shows how SA is related to decision making, which will be further discussed in Section 4.4.

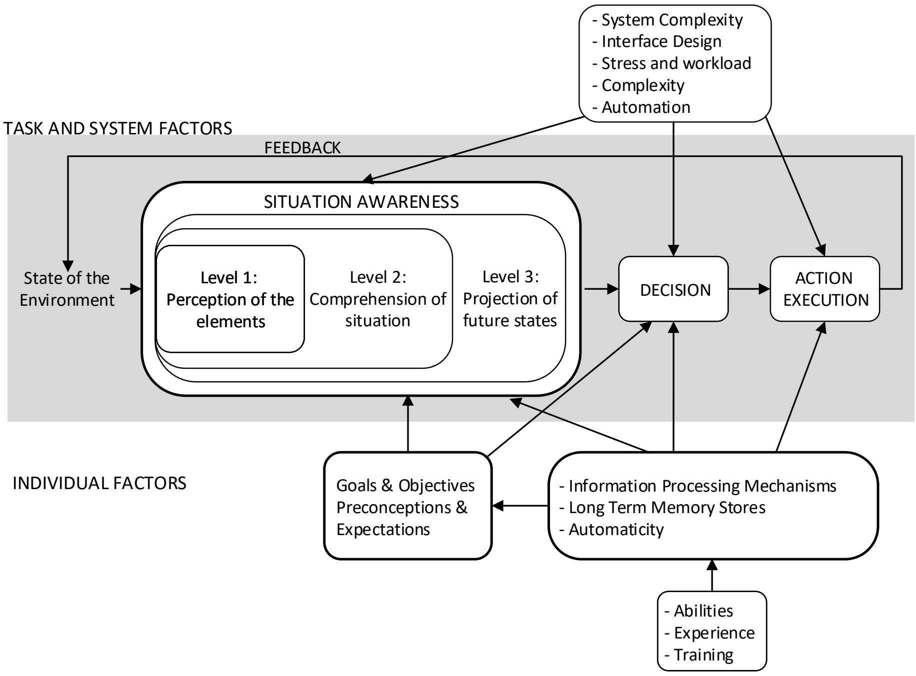


Figure 4.1: Model of SA related to the decision making process. Adopted form Endsley [4].

4.2.1 Level 1: Perception

According to Endsley [4], perception of the status, attributes, and dynamics of the environment's functional elements is required to achieve SA. The elements needed in situation assessment to gain SA changes with the domain. For the Chief Mate, elements can be defines as position, speed, other ships, while the elements for a pilot contain other air crafts, flight data and terrain [1, 4, 6, 16]. Perception of the information occurs through a single sense or a mixture of the senses; sight, hearing, smell, taste, and touch, as illustrated in Figure 4.2. It can be achieved directly through the senses or indirectly through displays, and user interfaces [4, 6, 47]. In addition to the importance of the information, the level of reliability of the information is crucial in Level 1 SA, to distinguish good and bad information [6].

Even if Level 1 seems simple, it is vital for understanding a situation and gaining awareness. Jones and Endsley [62] found that 76 % of the reports including "Situation Awareness" from the Aviation Safety Reporting System (ASRS) were due to Level 1 errors. Gaining perception of all the elements in a complex system can be challenging as much data is available.

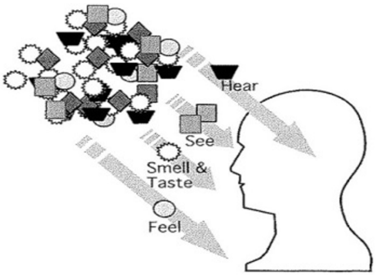


Figure 4.2: Illustration of which senses are used in the perception level to gather information [6].

4.2.2 Level 2: Comprehension

Indifferent to Level 1, Level 2 requires comprehension of the situation based on the elements perceived in Level 1. In order to comprehend the information, a holistic picture of the environment is created based on the elements. Mental models are used to understand the importance of the perceived information concerning the relevant goals and objectives, as illustrated in Figure 4.3. Existing knowledge and experience are used to evaluate and prioritize the perceived information in relation to goals and objectives [4, 6, 47]. Endsley [6] describes Level 2 SA as "...analogous to having a high level of reading comprehension as opposed to just reading the words."

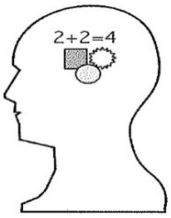


Figure 4.3: Illustration of the comprehension of the SA requirements [6].

As stated in the paragraph above, Level 2 awareness results from prior knowledge and experience. Suppose the position of the ship differs from to the predefined path. In that case, the Second Mate, which is in charge of navigation, must evaluate whether or not the ship must redirect towards the predefined course or if it is safe to continue on the path [16]. A novice Second Mate and an experienced Second Mate may achieve the same Level 1 SA, but while the experienced Second Mate assesses the various elements in the light of the goals to achieve Level 2 SA, the novice Second Mate may fall short due to lack of experience and mental models.

Even though Level 2 SA is based upon both knowledge and experience, Jones and Endsley [62] found that only 20 % of the errors identified in reports from Aviation Safety Reporting System (ASRS) were due to Level 2 SA errors [6, 47].

4.2.3 Level 3: Projection of the future

Endsley [4] defines the Level 3 SA as "the ability to project the future actions of the elements in the environment - at least in the very near term ....". A good understanding of the elements is required to project the future states. In other words, a good Level 1 and 2 SA is necessary. As mentioned in Section 4.2 the Three Level Model is not a sequential model, meaning that all the levels of SA change dynamically based upon changes in the environment and available information. Also, predicting what will not occur is a part of the prediction done in Level 3 [4, 6, 47]. An illustration of the Level 3 SA is shown in Figure 4.4 below.

Figure 4.4: Illustration of how the SA requirements are used to prodject future states [6].

Updating the highly developed mental models used to project future actions can be mentally demanding. According to Endsley [6], experts devote a considerable amount of time to form and improve their Level 3 SA. An example of projecting future states in ship navigation is the constant projection of other ships' movements, and anticipation of future problems performed by the ships' crew and the Vessel Traffic Service (VTS) [6, 16]. As presented in Section 4.2.2 the Level 2 SA can differ between experienced and novice operators. In order to achieve Level 3 SA a good Level 2 SA is required. In other words, experienced operators are better suited to acquire Level 3 SA than novices [4, 6, 47]. Of SA related incidents found in ASRS less than 4 % were due to Level 3 errors [62].

4.2.4 Human errors in the Three Level Model

Jones and Endsley [62] created a taxonomy of the errors related to the different levels in the Three Level Model with the basis of a literature review of human information processing and cognition. Based upon both the taxonomy made by Jones and Endsley [62] and the literature review by Salmon et al. [47] Table 4.1 presents the human errors in the different levels of SA.

Table 4.1: Types of human errors in the different levels of the Three Level Model [47, 62].

Level 1
•Failing to perceive information
•Misinterpret information
•Data is not available
•Memory limitation
•Failing to monitor and observe data
Level 2
•Failing to integrate or comprehend information
•Using incorrect mental model
•Lacking or incomplete mental model
•Over-relying on default values
•Other
Level 3
•Lacking or incomplete mental model
•Over-projecting current trends
•Limitations in mental simulation
•Other

In order to reduce the risk of human error in the three levels in the Three Level Model, the systems must be designed around the different elements presented in the taxonomy in Table 4.1.

4.3 Team Situation Awareness and Shared Situation Awareness

The following section will describe how SA relates to teamwork, whether or not the team members are working in the same location, with different tasks or have a lot of overlapping tasks. There exist at least three different types of SA in teams, which all depend on the team members' location and overlapping tasks. The main difference between the types of SA is to what extent the team members share SA requirements. SA requirements are defined by Endsley [6] as the dynamic information which is needed to perform the given work. In other words, the information which changes while working. To clarify the differences between the terms Team SA, Shared SA and Distributed SA, they will be described in detail in the following sections.

4.3.1 Definition of team

According to Gatenby [63] the first theoretical traditions of teamwork occurred in the time period before, under and after the Second World War. In the 90s researchers claimed that teams would be vital in organizations, and that teams would be the building blocks for the performance of future companies [64, p. 114].

Contu and Pecis [64] defined a team as "a small number of people with complementary skills who are committed to a common purpose, perform goals and approach which they hold themselves mutually accountable. The team has a joint specific collective work-products'...". While Salas et al. [65] defined teams as "a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership". In other words, the teams' goal, interdependence and the team members specific roles are the important features in a team [47, 66].

4.3.2 Team Situation Awareness

Even though Team SA and Shared SA are used interchangeably they are defined differently. There have been proposed multiple definitions of Team Situation Awareness (Team SA). Salas et al. [67, p. 131] defined Team SA as "the shared understanding of a situation among team members at one point of time" in their model of Team SA, while Endsley [4] defined Team SA as "the degree to which every team member possesses the SA required for his or her responsibilities." In relation to the definition by Endsley [4], Nofi [68] defined Team SA as "a shared awareness of a particular situation". As the Three Level Model by Endsley [4] is used as the foundation in this thesis, Endsley's definition of Team SA will be described further and used as a basis in this thesis. For further reading on other Team SA models the reader is revised to Salmon et al. [47, p. 21-23].

As defined by Salas et al. [67], team members are assigned specific roles. The team members have different subgoals and responsibilities with different roles, which feed the overall team goal. The elements and situations to perceive, comprehend, and project is different in the respective roles. Although the team members have different roles, some elements and responsibilities overlap. Based on the different elements and responsibilities related to the respective roles, each team member acquires their individual SA. In order to reach the overall team goal, each team member must gain SA for their respective SA requirements through situation assessment [4, 7, 50, 66].

The Team SA can be developed and maintained through verbal or non-verbal communication, a shared environment, or shared displays. There exist multiple tools within these methods of information-sharing. The information can be shared face-to-face, through video, audio, radio, chats, and shared folders, among others [66]. As the Endsley [4] definition states, Team SA is the degree of SA acquired by the team for their roles and responsibilities. Figure 4.5 visualizes Team SA with three team members, where the team members are interdependent, and have overlapping sub-goals [4, 6, 7, 50, 66].

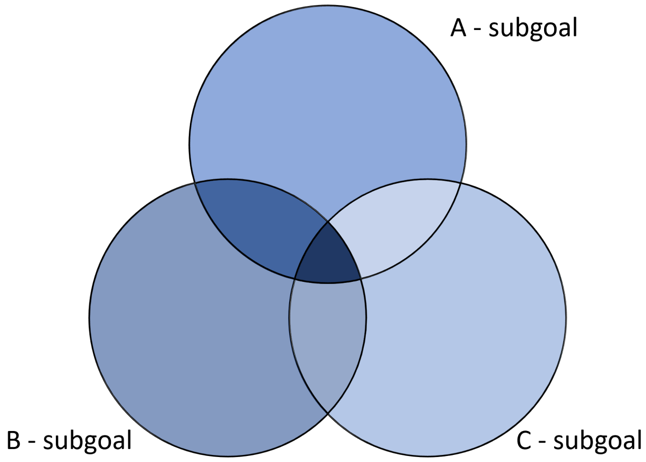


Figure 4.5: Representation of the sharing of SA requirements in Team situation Awareness. Adopted from Endsley [4].

If one of the team members is lacking SA, this affects the Team SA, as the Team SA is not stronger than the weakest link. For instance, on a ship, the Captain and the Chief Officer need to know some specific information. Suppose the Chief Officer has the information but not the Captain, who is in command of the ship. In that case, the Team SA is deficient, and their performance may deteriorate if the Captain does not obtain the missing information.

4.3.3 Shared Situation Awareness

In large and complex systems, the amount of information needed to gain individual SA can become quite extensive, and gaining Team SA can become even more extensive as the amount of information to be shared can constitute an overload [50]. Due to the potential overload on the team members when Team SA is used Endsley and Jones [7] presented Shared Situation Awareness (Shared SA).

Shared SA is defined by Endsley and Jones [7] as "the degree to which team members possess the same SA on shared Shared SA requirements." The difference between Team SA and Shared SA is the information amount and to what extent the information is shared between the different team members. All team members who perform Shared SA only share the information needed to gain a common understanding of the Shared SA requirements. Shared SA requirements are defined as the information form all SA levels that is shared between team members [6, 7]. In order to gain Shared SA, information from all three levels in the Three Level Model must be shared, perception of data, comprehension, and projections. The Shared SA requirements can be interpreted as the team's overlapping goals, as shown in Figure 4.6 [6, 7]. The colored parts in Figure 4.6 present the overlapping goals for three team members.

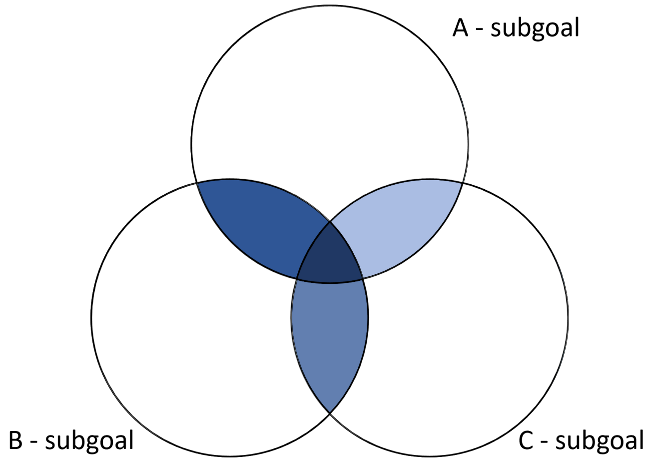


Figure 4.6: Representation of the sharing of SA requirements in Shared situation Awareness. Adopted from Endsley and Jones [7].

The team members who possess the Shared SA do not share all information they have encountered; only the information they have in common is shared. I.e., the participants in a Search and Rescue (SAR) mission all need to know the coordinates of the situation, ETA of the different participants, and descriptions of the situation. The participants who are already at the scene need information about the position of each other and their search area, but they do not need to know the status of the different ship's machinery.

The Three Level Model in Shared SA

The SA requirements for each team member is a function of their sub-goals and can therefore be quite specific. Along with the team's changing operations, the SA requirements also changes accordingly. Endsley and Jones [7] and Endsley [69] state that even though the SA requirements vary, they generally fall into the categories listed in Table 4.2. As stated in the paragraph above, all the three levels of the Three Level Model must be shared. The general data about the system or environment is essential. However, information about other team members might be shared as their previous actions or capabilities can affect another team member's SA [7, 69]. There exist multiple methods to present and communicate the information, both visual and auditory, and others

Table 4.2: Shared information/requirements in Shared SA. Adopted form Endsley [69].

Data
•System
•Environment
•Other team members
Comprehension
•Status relevant to own goals/requirements
•Status relevant to other's goals/requirements
•Impact of own actions/changes on others
•Impact of other's actions on self and mission
Projection
•Actions of team members

Additional to the general data, the higher level Shared SA regarding the team members' evaluations of the situation is vital and must be distributed across the team. As the team members' roles are interdependent, the Level 2 Comprehension is crucial. The team members need to share a common understanding of how their task status and actions impact the other team members and how other team members' task statuses and actions impact their own tasks in light of both the sub-goals and the overall team goal. As a result, when some team members have acquired Level 2 Shared SA, this also needs to be shared. Generally, all the three levels of Shared SA should be shared within the team.

Endsley and Jones [7] and Endsley [69] state that "in a highly functioning team, team members can project not only what will occur with their system and external events, but also what fellow team members will do." Projecting the other team members' activities in different situations, including their way of working, where they will be located, and what complications or problems they might struggle with, can increase the team's effectiveness [7, 69].

Possible outcomes of Shared SA

The following section will describe the three possible outcomes after a team has acquired Shared SA; these outcomes are presented in Figure 4.7. The light-colored circles represent incorrect SA, while the dark-colored circles represent correct acquired SA. Figure 4.7 is described further below with the basis of two teams members.

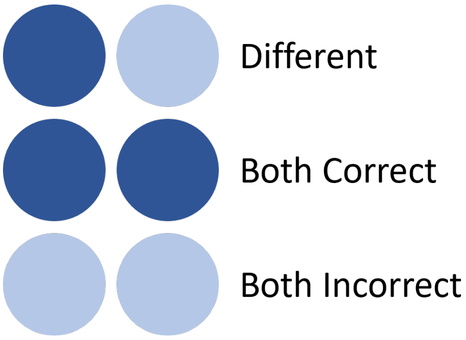


Figure 4.7: Possible outcomes of Shared SA. Adopted from Endsley and Jones [7].

The first outcome presented in Figure 4.7 one light blue circle and one dark blue circle represents the Shared SA of the two team members, whereas one has obtained the correct Shared SA, while the other has obtained an incorrect Shared SA. This outcome can occur if the two team members have different mental pictures of the situation. Through good communication, use of different communication methods and continuous updates of Shared SA the team members can detect the misconception and resolve the differences in Shared SA. If the misconceptions are not detected the results can be fatal [6, 7, 69].

On November 8th 2018 the military frigate HNoMS Helge Ingstad collided with the oil tanker Sola TS outside the Sture Terminal in Hjeltefjord, Norway. The accident was investigated by Accident Investigation Board Norway (AIBN) and Defence Accident Investigation Board Norway (SAIBN). HNoMS Helge Ingstad was sailing with the Automatic Identification System (AIS) in passive mode, meaning they did not transit any AIS-signals. From part one of the accident report, it is clear that most of the crew on HNoMS Helge Ingstad thought that Sola TS, which had all her forward-pointing deck lights on, was a stationary object like a quay, fish farm or a rig/platform which they would pass on their starboard side [5].

On the other hand, Sola TS knew that there was a ship that would cross their course line but had no information about the ship. In this situation the crew on HNoMS Helge Ingstad and Sola TS had different understandings of the situation, meaning their Shared SA was different. This difference in Shared SA led to the collision, whereby HNoMS Helge Ingstad later ran aground and subsequently sank [5].

The second possible outcome, and the most preferred one, is the outcome when both team members have acquired the correct and same Shared SA. This type of Shared SA is the ultimate goal, and is presented in Figure 4.7 as two dark blue colored circles. In order to achieve this outcome, good communication and supporting technologies are vital [6, 70]. Robertson and Endsley [70] state that there have been developed techniques in the commercial aviation sector, called Bridge Resource Management (BRM), to help the crews share the best attainable understanding of the situation. The possibility of two team members having the correct but different Shared SA is found to be impossible as Shared SA only concerns the Shared SA elements. In other words, when everyone shares the same Shared SA, the risk of human errors is reduced drastically [6, 70].

The last and most dangerous outcome of Shared SA is when the team members have the same but incorrect Shared SA. The outcome is represented in Figure 4.7 as two light blue colored circles. As the team members have acquired the same Shared SA, there will be no immediate indications that there is a problem with the Shared SA which needs to be resolved. According to Endsley and Jones [7] the team members' incorrect picture of the situation will remain until some external event alters it. The incorrect Shared SA is dangerous because while the incorrect Shared SA remains, the situation can worsen. When the team members recognize the discrepancy between their Shared SA and the actual situation, it might be too late to prevent an incident [6, 7, 69].

In the accident between HNoMS Helge Ingstad and Sola TS mentioned above, the crew on HNoMS Helge Ingstad shared the same incorrect Shared SA. The crew thought Sola TS was a stationary object like a quay, fishing farm, or rig/platform. Different factors led to this conclusion; Sola TS had her forward-pointing deck lights on, so it was hard to see her navigation lights, the relieving Officer of the Watch (OOW) and the OOW to be relieved saw the object's AIS-signals on the radar. However, no speed vector was associated with it; therefore, the object was not tracked. Even though both OOWs state that they saw Sola TS's AIS signals, they both concluded it had to be from a stationary object. From this point out, the crew had an incorrect Shared SA. Due to confirmation bias and not getting any new information that disputed their mindset, the same Shared SA was retained until less than a minute before the collision occurred [5].

4.3.4 Distributed Situation Awareness

In Section 4.3 Team SA is discussed in teams which are in the same environment, and share a common goal. Due to the technology supporting communication and networking, the teams might be distributed in different rooms, structures, countries, or working in different time zones or shifts. Examples of distributed team are the Vessel Traffic Service (VTS), commercial ships, and the coast guard. The commercial ship and the coast guard are not located in the same area at the beginning of a Search and Rescue (SAR) mission, while the VTS might be stationed far away from the situation. In these distributed teams, the environment surrounding the team members is different, but they share a joint goal. Endsley and Jones [7] defined Distributed Situation Awareness (Distributed SA) as "SA in teams which members are separated by distance, time, and/or obstacles". This theory must not be confused with the Distributed Situation Awareness (DSA) presented by Artman and Garbis [71].

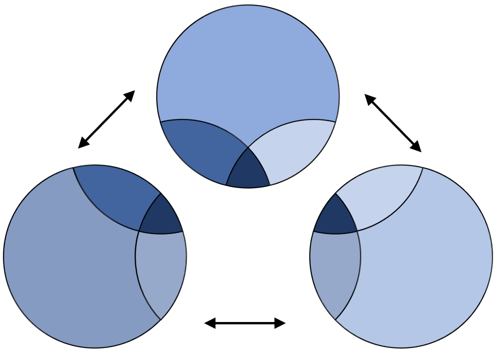


Figure 4.8: Shared SA in Distributed Teams. Adopted form Endsley and Jones [7].

The SA requirements for Distributed SA and Shared SA are mostly the same. As Figures 4.6 and 4.8 show, the requirements for both distributed and co-located teams are mainly the same, with overlapping requirements. Nevertheless, the difference between distributed and co-located teams is that distributed teams are faced with the complication of not being able to use non-verbal communication and do not share a common environment, as shown in Table 4.3. Using voice communication or shared displays can be challenging and produce an extra workload. This communication also includes the workload on the team members and stress levels, which can be hard to share in distributed teams. Even though some of this information can be shared through voice communication and shared displays, Endsley and Jones [7] specify that humans rely a lot on communication through physical presence. Finding technology and other solutions to share the information lost through not being in the same environment and not being able to use non-verbal communication is vital to ensure good Shared SA in distributed teams.

4.3.5 The process of gaining Shared SA

The theory of Shared SA and the importance of all participants gaining the correct Shared SA have been presented. In order to gain Shared SA the Shared SA requirements must be processed in the situation assessment. The following Section will describe the process of gaining Shared SA.

Table 4.3: Different devices which can be used to gain Shared SA within a team. Adopted from Endsley and Jones [7].

Communication
•Verbal
•Non-Verbal
Shared Displays
•Visual
•Audio
•Others
Shared Environment

In the situation assessment process, multiple devices can be used to develop Shared SA. Table 4.3 presents some of the different devices. Firstly, communication between the team members can be used, both verbal and non-verbal. The team members can communicate verbally to share information or perspectives on the situation. However, they can also communicate non-verbally with body language such as facial gestures and pointing [6, 7].

Secondly, shared displays can be used to establish Shared SA. The shared displays can be used to show the different team members information, which is vital for gaining correct Shared SA. For example, a Radio Detection and Ranging (RADAR) can be used in the maritime environment as a shared display where all team members can precept and comprehend the traffic situation and project future situations. As it can be seen from Table 4.3 the Shared SA requirements can be displayed through visual displays (paper, RADAR), auditory displays (alarms, text-to-speech) or other displays which are based on human senses such as touch and movements [6, 7].

Lastly, a shared environment is one of the devices presented in Table 4.3. The need to share information through the other devices disappear by being in the same environment. For example, a bridge crew does not need to inform each other that traffic density is high, as all the crew members are in the same environment [6, 7].

The devices described above can all be used in teams in the same environment, but when the team is distributed, some methods are unattainable. For instance, as the team members are not sharing the environment, the environment must be described and shared through the other methods presented in Table 4.3. The methods can be combined to present information in the best possible way [6].

Even though the devices presented in this section can be used to gain Shared SA, interpreting the information is just as vital. The different outcomes of Shared SA and the consequences related to them are thoroughly explained in Section 4.3.3.

4.4 Situation Awareness and Decision Making

In Section 4.3 the theory and examples of Team SA, Shared SA, Distributed SA were defined and presented. In the following section, SA will be described in relation to decision making and action execution.

4.4.1 Orient, Observe, Decide, Act - OODA-loop

Colonel John Boyd created the Observe, Orient, Decide, Act loop (OODA-loop) shown in Figure 4.9 [69, 72]. The OODA-loop was originally created to understand the decision-making process in the aerial battles like dogfightS, where the pilots must first detect enemy air crafts as an action of observing the environment, then orient the aircraft towards the enemy, decide what should be the next step and lastly act upon the decision which is made [69, 73, 74].

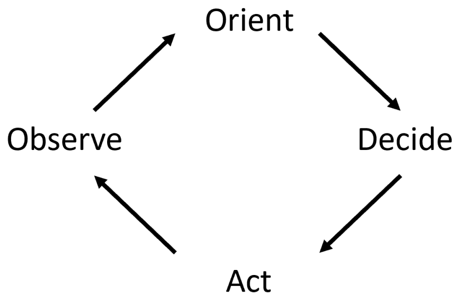


Figure 4.9: The Observe-Orient-Decide-Act (OODA) loop for decision-making. Adopted form Endsley [69].

Colonel Boyd changed the loop to a model where multiple loops are interfering. Even though the OODA-loop was created for situations within air-to-air fighter combat the model can be generalized to apply to decision-making in any field [72]. The first step in the model is to observe the environment through collecting information about the current state of the environment, through using the visual, auditory, tactile, taste and olfactory senses, and the devices which are based on the mentioned senses [73, 74].

The second step in the model is *Orienting*, by Boyd referred to as the focal point of the model [73, p. 29]. Through the use of existing knowledge the collected information is interpreted, and the model of the environment or situation is changed accordingly. Besides the existing knowledge, new information, cultural traditions, genetic heritage, and experiences are also forming and changing the model of the environment or situation [73, p. 29]. Therefore, individuals with diverse backgrounds and experiences can interpret the same information differently.

With the updated model of the environment or situation, predictions of future states and the decision of what actions should be performed can be made, which is the third step in the OODA-loop. The OODA-loop does noe restrict the user to any decision-making method. After a decision is made, the last step is to perform the action. The action usually affects the state of the environment or situation, and the OODA-loop alters as a feedback loop between the decision making process and the environment[73, 74].

4.4.2 Situation Awareness, Decision, Action - SADA-loop

In the following section, the Situation Awareness, Decision, Action loop (SADA loop) will be described and defined as a combination of Colonel Boyds' OODA-loop and Endsley's SA model. The two first steps, *observe* and *orient*, in the OODA-loop, are described by Poisel [73] to concern the gathering of information about the environment and the analysis and interpretation of the gathered information. The Three Level Model also consists of gathering information and its perception and comprehension.

Additionally, the Three Level Model also includes the projection of future states, which can provide vital knowledge before making a decision. Compared to *observe* and *orient* in the OODA-loop, the Three Level Model is identical if not improved as it also includes the projection of future states. Figure 4.10 illustrates the SADA loop where decision support might be needed to determine which decision is the preferred one. As this thesis revolves around Situation Awareness, the SADA loop will be used as a basis.

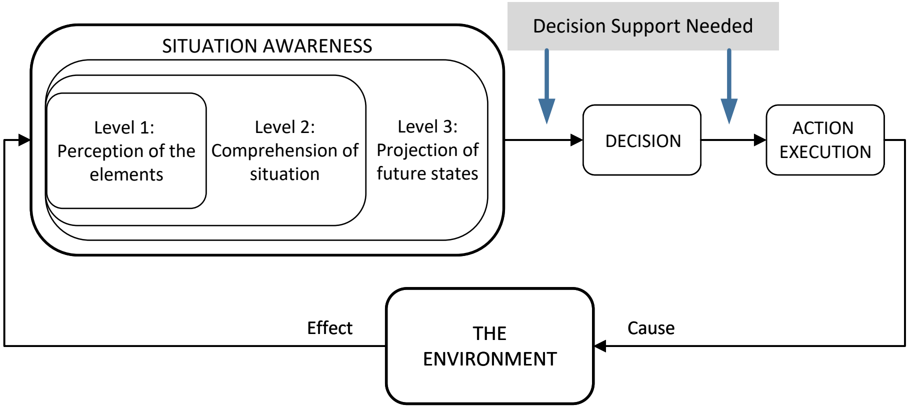


Figure 4.10: The correlation between the Three Level Model and the Situation Awareness, Decision, Action loop (SADA loop). Adopted from Lectures by Thor Hukkelås and Endsley [6].

As Figure 4.10 shows, the Three Level Model is carried through before a decision is made, and action executed. After the chosen action is executed the cause-and-effect is perceived, comprehended and used to project future states on the next loop.

4.5 Critique and Response of the Three Level mOdel

As some researchers disagree with the definition of SA proposed by Endsley [4], other disagree with the SA model in the decision-making process by Endsley [4] as shown in Figure 4.1. Some of these researches have formed new models for SA [50].

Although the Three Level Model is widely recognized, other researchers have criticized it on various grounds. Endsley [50] presents and responds to critique raised towards the Three Level Model in the article *'Situation Awareness Misconceptions and Misunderstandings'*. Endsley states that the critique based on misconceptions and misunderstandings of the Three Level Model creates confusion around the model. The fallacies mentioned in the paper are the linearity of the three levels of SA, the model being a data-driven information-processing model, SA being the process of gathering and processing information, the model not being cyclical nor dynamic, it failing to make meaning of the information into account, only basing the SA on the working memory and lastly, the model being "in-the-head" and not encompassing the wider socio-technical environment [50].

Chiappe et al. [75, p. 642] have proposed a theory called *Situated Situation Awareness*, which states that "the situated SA approach holds that operators maintain their understanding of dynamic situations by relying on minimal internal representations and engaging in frequent interactions with a structured environment. Operators sample limited amounts of information from the environment in cycles and extract its relevance by combining it with an easily accessible context, as per RT (Relative Theory)". Endsley [50, p. 16] discusses that the theory is based on misconceptions and misunderstandings of the Three Level Model. The most evident misconception is used as a basis for deriving the new theory are the statements that the Three Level Model is a 'Cartesian' in-the-head model and that the model is limited by theory about linearity and information-processing. These misconceptions are disproved by Endsley [50].

The term *sensemaking* was popularized by Karl E. Weick according to Endsley [50]. Sensemaking can be defined as a method to update one SA. The method is retrospective, whereas, in retrospect, the information gathered from varying surroundings and the selection of mental processes are evaluated [5, Appendix G]. Endsley [50, p. 18] argues that sensemaking can be described as the "...the process of forming Level 2 SA from Level 1 data through effort-full processes of gathering and synthesizing information, using story building a mental models...". Therefore, sensemaking and SA are both similar and dissimilar. The main differences between the two terms are that while sensemaking is mainly backward-looking, searching for reasons for different situations, SA is forward-looking, using available information to predict future scenarios. For further reading on the comparison of the models, the reader is advised to *Situation Awareness Misconceptions and Misunderstandings* [50, p. 19-23].

4.6 Shared SA in the maritime environment

Communication between the participants presented in Chapter 2 will be between Shared and Distributed SA as some participants operate in the same environment while others are not.

Manned ships, autonomous ships and recreational crafts are able to obtain a Shared SA, while the joint SA between the sea-based participants and the ROC and VTS operators can be defined as Distributed SA. Nevertheless, as the ROC and VTS operators must share an understanding of the environment surrounding the sea-based participants, they can also be a part of the Shared SA. Nevertheless, to ease the terminology, it will be defined as Shared SA.

4.7 Out-of-the-loop syndrome

When the theory of Shared SA is related to complex automated systems as in Section 4.6 the Out-of-The-Loop (OTL) syndrome becomes vital. Whenever an automated system fails, the operators' task is to detect the problem, investigate the problem, and take actions, i.e., manually overwrite the system, just like a control system [6]. However, when "...the operator is no longer a part of the control loop and hence is unable to maintain control over the controlled system...," as described by the SITUMAR project in Kongsberg Maritime [76], the operator is OTL. The OTL syndrome can occur from a variety of errors, the lack of SA is described by Endsley and Kiris [77] as one of them. According to Endsley and Kiris [77] the loss of SA is usually due to the three mechanisms;

1. A loss of vigilance and increase in complacency associated with the assumption of a monitoring role.
2. A move from an active processor of information to a passive recipient of information.
3. A loss of or change in the type of feedback provided to operators concerning the system's state.

The OTL is closely related to the automaton paradox, which can be defined as "the more automation is added to a system and the more reliable and robust that automation is, the less likely that human operators overseeing the automation will be aware of critical information and able to take over manual control when needed [78]." In order to prevent an operator's loss of SA and possibly also the OTL syndrome, both the degree of automation and the system design is vital. The reader is advised to *Designing for Situation Awareness* by Endsley [6] for detailed information.

4.8 Goal-Directed Task Analysis

To gain SA, the user must process information collected through his/her senses or presented through the devices presented in Section 4.6. In order to gain a precise and accurate SA, the information or SA requirements must be relevant for the user in the specific environment or situation. As system designers usually determine the information provided through systems, the quality of the user's SA partly relies on the system designer's understanding of the environment or situation. All SA requirements must be found to ensure that the system designer knows what information the user needs and how the information should be presented.

In order to provide a comprehensive understanding of the environment or situation, Mica Endsley has presented a cognitive task analysis named Goal-Directed Task Analysis (GDTA). Endsley [6] states that "the GDTA focuses on the goals an operator must accomplish in order to perform the job successfully, the decision he/she must make to achieve the goal, and the information requirements that are needed in order to make appropriate decisions." The dynamic information needed by the user is referred to as SA requirements. The basis of the analysis is to understand what kind of dynamic information the user needs to make suitable decisions while disregarding the method or technology used to obtain the information. According to Endsley [6], by focusing on the information need and disregarding the method or technology used to obtain the information, the understanding of which SA requirements different users need is improved. [6].

The SA requirements can be found by combining information from literature, and interviews of experienced users, where the interviewee are asked questions like the ones listed below:

- What is your overall goal?
- What information do you need to make that decision?
- What decisions do you make to achieve your goal?

After making a rough sketch of the SA requirements, interviews of Subject Matter Experts (SMEs) should be completed to verify the found SA requirements. After the SA requirements are verified by one or multiple SMEs, the identified and verified SA requirements must be structured into overall goals, major goals, subgoals, decisions and SA requirements. The structured data can be filled into a Goal-Decision-SA requirement structure as shown in Figure 4.11 to easily display the results [6, 16]. As the method is independent of method and technology, the GDTA form can be used in the future.

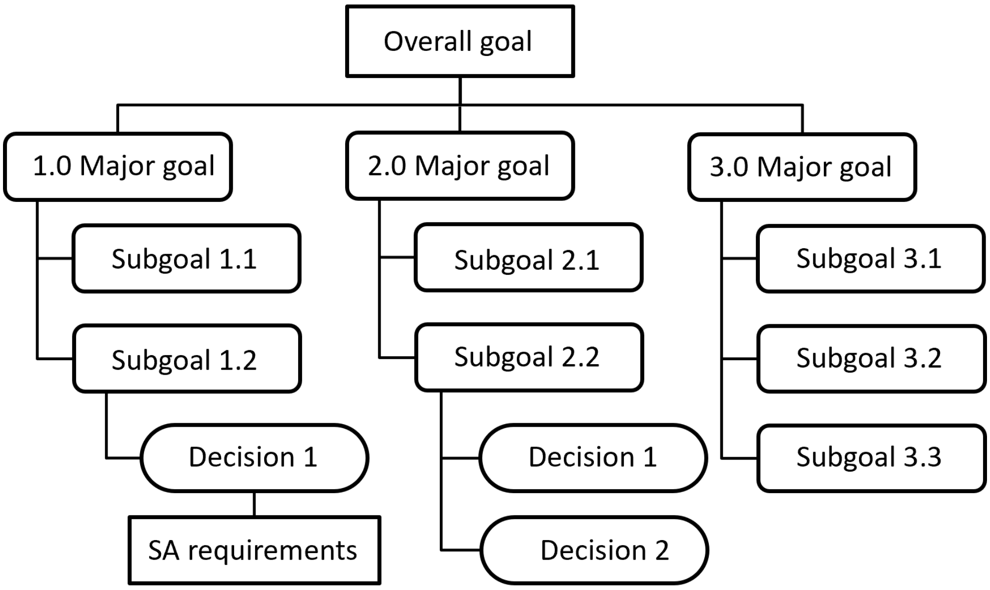


Figure 4.11: Chart used to structure goals, decisions and SA requirements identified through the performance of a GDTA.

Chapter 5

Shared SA requirements for maritime navigation

As presented in Chapter 1, the scope of the thesis is the SA required under navigation and maneuvering. In order to understand how the Shared SA between autonomous ships, manned ships, pleasure crafts, ROC and VTS arises, the SA requirements of the different participants must be found. It is vital to understand the participants' information needs to design and invent technology and methods which ensures Shared SA in maritime operations, especially when autonomous ships and ROC become participants in the Shared SA. The following sections will describe the method and identification of SA requirements.

To identify the SA requirements for the participants, an understanding of the different responsibilities and information the participants need to perform their work in the desired manner must be established. By conducting a GDTA as described in Section 4.8, the responsibilities and information needs of the different participants can be found. The method is remarkably time-consuming, as a literature review must be performed before interviews are planned and carried through. After that, the information from the interviews is analyzed, and experts must verify the findings. Due to the time-consuming execution of GDTA, there has been performed a literature review with basis on the GDTA.

To create a complete picture of the information need for the different participants, there has been performed a literature review on autonomous ships, manned ships, ROC and VTS which are thoroughly described in Sections 5.1.1, 5.1.2 and 5.1.4. The literature review and analysis results are presented in Section 5.3 where one of six information matrices is described, analyzed, and presented in detail. The full results, including all information matrices, can be found in Appendices A and B.

5.1 Method for identifying Shared SA requirements

The following section will describe the methods and literature used to identify the Shared SA requirements for the participants.

5.1.1 Manned ships

Understanding the shared information need for manned ships is vital for also understanding the information need for autonomous ships, ROC and VTS as they are performing the same tasks or they are supporting and guiding the manned ships. The following section will present the method used to identify the Shared SA requirements for manned ships.

To understand the information need in manned ships, the accident report of the HNoMS Helge Ingstad accident on November 8th, 2019 [5] and the GDTA analysis of maritime navigation performed by Sharma et al. [16] were analyzed. The incident report of the HNoMS Helge Ingstad accident consists of thorough descriptions of the activities performed on the frigate, tankship Sola TS and by the VTS. Further, it also includes thorough descriptions of which information HNoMS Helge Ingstad, Sola TS and VTS were missing and which actions or lack of actions led to the collision.

The GDTA performed by Sharma et al. [16] is based upon interviews of seven experienced navigators (mean age of 27.9 years, with a standard deviation of 4.4) and verification interviews by three Subject Matter Experts (SMEs) which possessed Captain's licenses [16]. The results include both goals and Shared SA requirements.

Shared SA requirements from HNoMS Helge Ingstad

As stated above, the first accident report of HNoMS Helge Ingstad includes thorough descriptions of missing information and actions or lack of actions in the hours leading up to the accident; for example, "...the Officer of the Watch (OOW) had not yet identified or understood that the 'object' was, in fact, a moving vessel ..." [5, p. 127]. The descriptions vary between conversations, thoughts, activities, general descriptions, or descriptions of sequences of events in different time intervals.

Analyzing the accident report's descriptions, the SA requirements could be identified, i.e., the quote below.

> 'They talked about forecast weather conditions with rising winds and increasing wave heights into the day and reviewed the bridge system, radar, and communication settings.' [5, p. 16]

The conversation is from the handover between the OOW being relieved and the relieving OOW 8-16 minutes prior to the collision. From the quote, it is clear that they are discussing the weather forecast and hydrographic measurements. The OOWs are responsible for the navigation of the frigate; hence, the information shared in the handover between them is essential for the navigation. In other words, weather conditions and hydrographic measurements like wind and wave heights can be identified as SA requirements. After identifying an SA requirement or an activity, it was placed in a table as shown in Table 5.1. The table presents some of the SA requirements and activities found through analyzing the accident report.

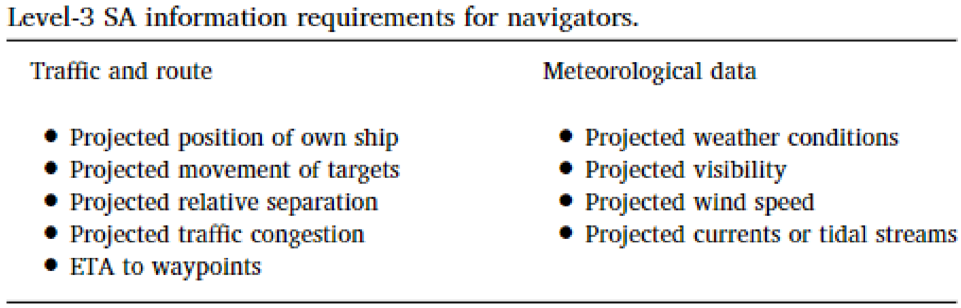
Table 5.1: Excerpt of list of SA requirements identified through the accident report of HNoMS Helge Ingstad.

Helge Ingstad - SA requirements
•Weather conditions
•Hydrographic measurements
•Request to enter/exit VTS area
•AIS signals
•Visual contact
•Verification of objects (i.e navigation lights)
•Visual observation of ship, verification through radar/AIS signals

It can be seen from Table 5.1 that the list includes SA requirements as 'Weather conditions' and 'AIS signal', but also activities as 'Visual observation of ship, verification through radar/AIS signals'.

Shared SA requirements from Goal-Directed Task Analysis

As presented in Section 5.1.1 Sharma et al. [16] performed a GDTA on maritime navigation. Their results are presented in forms of goals and SA requirements, where the SA requirements are sorted into Level 1, Level 2 or Level 3 SA requirements according to the Three Level Model and groups defined in the article by Sharma et al. [16]. In addition to the SA requirements, Sharma et al. [16] defined navigators goals during pilotage. Figure 5.1 displays a screenshot of the Level 3 SA requirements, with the groupings 'Traffic and route' and 'Meteorological data'. As the results are the SA requirements, there was no need to process the results, and their results were combined and compared to the findings from the HNoMS Helge Ingstad accident report.



Level-3 SA information requirements for navigators.

Traffic and route	Meteorological data
• Projected position of own ship	• Projected weather conditions
• Projected movement of targets	• Projected visibility
• Projected relative separation	• Projected wind speed
• Projected traffic congestion	• Projected currents or tidal streams
• ETA to waypoints	

Figure 5.1: Screenshot of Level-3 SA requirements results found by Sharma et al. [16] through a GDTA.

Combining SA requirements from HNoMS Helge Ingstad and GDTA

The SA requirements from the HNoMS Helge Ingstad accident report and the SA requirements found through the GDTA by Sharma et al. [16] must be compared and combined to ensure covering most of the existing SA requirements.

A table was made to compare the SA requirements for each of the sources where the SA requirements from the GDTA were grouped after the goals defined by Sharma et al. [16], and the SA requirements from the HNoMS Helge Ingstad accident report were grouped after goals and tasks found in the accident report. In addition, as 'AIS signals', which are dependent on the technology, were identified as an SA requirement the information included in AIS signals was defined as in the guideline for AIS created by IMO [79]. Table 5.2 shows an example of the groupings for the two sources. The tables will be used later in Section 5.2.1 as a basis for producing the information matrices.

Table 5.2: Excerpt of grouping of SA requirements from HNoMS Helge Ingstad report [5] and GDTA by Sharma et al. [16] after goal and tasks.

	Goal	Task	SA requirement
GDTA by Sharma et al.	Determined the route to be followed	Assess route plan	Planned route
			Distance to waypoints
			Planned speed for each leg
			Air draft
		Discuss contigency measure	Anchorage areas
HNoMS Helge Ingstad	Being updated on traffic or other elements in the area	Visual verification	Navigation lights
		Weather conditions	Visibility
			Temperature
			Wind speed
			Wind direction
			Current/tidal stream direction/speed

5.1.2 ROC and Autonomous ships

Several projects concerning autonomous ships and their respective ROC have been performed to make the shipping industry more competitive and sustainable [29, 80, 81]. When the autonomous ship is autonomously controlled, it must maintain its SA and part of the Shared SA. However, when the ship is remotely controlled through ROC, the operators must inherit the same SA and part of the Shared SA.

The environment surrounding the autonomous ships is the same as for the manned ships, meaning that some of the SA requirements for the autonomous ship will be similar to those needed by manned ships. On the other hand, the situations the autonomous ship might be exposed to can differ from manned ships as there is no crew onboard to consider. Further, the operators in the ROC will have to obtain the same SA as the crew on a manned ship while being located elsewhere, which demands that all information needed to obtain the same SA is available.

To identify the SA requirements an understanding of the environment and situations the ship and the operators will face must be formed. Due to there being some similarities between the manned ship and the autonomous ship or ROC as portrayed in Section 5.1.1 the SA requirements for manned ships are used as a source of information. In addition to the SA requirements for manned ships literature regarding ROC and remote operations are used to identify the SA requirements.

The two articles from the MUNIN project *'D4.5: Architecture specification'* [22] and *'D8.8: Final Report: Shore Control Centre'* [33] are used as literature basis. The articles contain descriptions for the concept of ROC, tests of different hypotheses related to the ROC operators' SA, workload and time to get into the loop, the baseline for autonomous voyage and different control modes. Furthermore the articles *'Situation Awareness in Remote Operation of Autonomous ships'* by Ottesen [82], *'No-one in Control: Unmanned Control Rooms for Unmanned Ships?'* by Porathe [34] and *'Human Factors, autonomous ships and constrained coastal navigation'* by Porathe et al. [83] were used in addition to the MUNIN articles to identify the SA requirements for autonomous ships and ROC.

Ottesen [82] introduces guidelines for ROC where a presentation of needed data and creating a reliable human/autonomy symbiosis is the main focus. The article by Porathe [34] discusses how the human shortcomings must be taken into account when designing the systems for interaction between autonomous ships and ROC. He especially discusses the out-of-the-loop syndrome described in Section 4.7 and information overload or underload. Besides focusing on the HF in navigation in national coastal waters, the concept paper by Porathe et al. [83] focuses on the interaction between automation, the ROC operators and seafarers on conventional ships.

Through analyzing the five papers with the same method explained in Section 5.1.1 there was identified SA requirements and tasks for autonomous ships or ROC operators. Table 5.3 presents the literature where SA requirements are identified from.

Table 5.3: List of articles used to identify the SA requirements for autonomous ships and ROC.

MUNIN articles	
MacKinnon et al. [33]	Rødseth et al. [22]
•COLREG	•Weather and hydrographic measures
•Planning and uploading voyage plan	•Port instructions
•Operational abnormalities	•Restricted operating area
Other articles	
Ottesen [82]	Porathe [34]
•Ship motion pitch/roll	•COLREG
•Route planning	•Weather conditions
•Control mode	•Availability status for ROC operator
Porathe et al. [83]	
•Availability status for ROC operator	
•Potential traffic conflicts	
•Ship motion (i.e roll, pitch, heave)	
•Identification tag of control mode	

As it can be seen from Table 5.3 the different papers both introduced new SA requirements, but also verified one another. After the SA requirements were identified and verified they were grouped after goals and tasks found in the respective articles and inserted into a Table similar to Table 5.2.

5.1.3 Recreational crafts

There exist many different types of recreational crafts. As described in Chapter 2 recreational crafts are not subjected to the same laws as the other sea-based participants, where many of the laws they are not subjected to are related to equipment, i.e., VHF radios and AIS systems [84, 85].

In an ideal world, recreational crafts will have the equipment to transmit and receive the same Shared SA requirements as manned ships. As the identification of Shared SA requirements is performed independently from available technology, the Shared SA requirements identified for manned ships are also used for recreational crafts with small modifications. The modifications are only related to VTS as recreational crafts are not required to report to VTS [86].

5.1.4 VTS

The VTS is essential in maritime operations as they offer the services Information Service (INS), Navigation Assistance Service (NAS) and Traffic Organization (TOS). As a result the VTS are helping the manned ships, autonomous ships, recreational crafts and ROC to maintain or obtain a satisfactory Shared SA, and the Shared SA requirements they provide must be identified [39].

In order to identify the information needs for the VTS the HNoMS Helge Ingstad accident report [5], the Norwegian Coastal Administration (NCA) information pages about VTS [87] and the guidelines defined by IMO [38] were analyzed. The accident report includes thorough descriptions of the activities performed on Fedje VTS in the time around the accident. In addition, it consists of information about regulations, tasks, services and competence requirements related to the VTS [5]. While the NCA information pages and the IMO guideline includes details about VTS services, navigation rules, requirements for vessels operating in VTS areas, etc. [87].

The material found in the three sources was analyzed in the same manner as the accident report for manned ships, described in Section 5.1.1. As the sources contained some of the same information, the sources were compared against each other, as shown below. The first quote is taken from the accident report, where the VTS"s tasks were presented in bullet points in the accident report.

> "... granting sailing permission to vessels before they enter
> the VTS area and before they leave port ..." [5, p. 75]

As stated in the quote above, one of the responsibilities of the VTS is to grant entering/exit clearance to vessels. Some SA requirements can be found from knowing the task. In order to grant the vessels the clearance, the VTS must at least know which vessels are entering/exiting and where it is entering/exiting the VTS area. A resulting SA requirement is, therefore, 'AIS signals' as the AIS contains both the ship identification and the vessel's position. After finding the SA requirements it can be cross-referenced with the section in the action report where the VTS systems are described [5, p. 79].

The second quote is from the NCA and compared to the quote from HNoMS Helge Ingstad, it can be seen that they state the same information. As a result, 'AIS signals' can be defined as a SA requirement.

> "... Giving clearance to vessels before entering the VTS area
> and before leaving the anchorage position or port ..." [37]

After verifying the identified SA requirements, they were written into a Table, identical to the one presented in Table 5.2. The SA requirements are organized in goals and tasks, in the same manner as the SA requirements for manned ships.

5.2 Method for creating information matrices

Shared SA is defined as "the degree to which team members possess the same SA on Shared SA requirements" [7]. To define the Shared SA requirements all the individual SA requirements must identified. In Sections 5.1.1 to 5.1.4 the method used to identify the Shared SA requirements for manned ships, autonomous ships, recreational crafts, ROC and VTS was described. In the following section, the Shared SA requirements needed to obtain Shared SA are identified from the lists of SA requirements created in Sections 5.1.1, 5.1.2 and 5.1.4, meaning that some SA requirements are dismissed. Communication and information sharing is vital in creating the same understanding of the environment. Chapters 6 and 7 will reveal the present and future methods and technology used to communicate and share the in the situation assessment.

The MUNIN project and the NFAS have defined a baseline for autonomous voyages, as described in Section 2.1. As it can be seen from Figure 2.1 and the description of the voyage phases, the control mode of the autonomous ship changes according to the voyage phases. From port until the end of the approach, the ship is manned, while in the transit phase between the two approach phases, the ship is unmanned. The control status can vary between *Autonomous control*, *Indirect Remote Control* and *Direct Remote Control* throughout the transit phase [22]. The participants and their Shared SA requirements vary along with the voyage phase and control status.

5.2.1 Information matrices

In order to present which Shared SA requirements the different participants share or need from each other to form an excellent Shared SA, information matrices were created. Table 5.4 displays the layout of an information matrix. The rows represent the receiving participants, while the columns represent the transmitting participants. In other words, the rows describe which SA requirements the one participant needs or should receive from the other participants.

The Shared SA requirements needed by the different participants are found by using the tables similar to Table 5.2. What kind of information the different receivers need from the transmitters in order to gain a satisfactory Shared SA is decided through the knowledge gained by analyzing the different articles and reports presented in Sections 5.1.1 to 5.1.4.

Table 5.4: Example of an information matrix used to described the Shared SA requirements needed from the different participants. The rows describe the information need for the horizontal participant from the participants in the columns. The Information Packs (IPs) X and Y contain grouped Shared SA requirements.

Task:

Transmitter / Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
Manned ship	X				
Autonomous ship		X			
ROC	IP X	IP X, IP Y	X		
Recreational crafts				X	
VTS					X

Both descriptions from regulations and actual situations are used to determine which Shared SA requirements the different receivers need from the transmitters. For instance, the HNoMS Helge Ingstad accident report presents Sections 7. and 11. in the Maritime Traffic Regulations, which concern the duty to listen, the duty of disclosure, and the communication in the VTS area [5, p. 75]. These regulations found that all ships must know the VHF frequency and that they are obligated to inform the VTS about the departure from the dock or anchorage site. On the other hand, that implies that the VTS needs this information from the ships.

The identified Shared SA requirements for the respective receivers are presented as Information Packs (IPs) as shown in Table 5.4 as *IP X* and *IP Y*. These IPs are created to ease the readability of the information matrices. The IP grouping will be thoroughly described in Section 5.2.2.

In Section 5.2, it is mentioned that the Shared SA requirements changes according to the voyage phase and control status. As a result, an information matrix was created for each voyage phase. As the control status can rapidly change in the transit phase, it was made an information matrix for each control status, meaning, in total, six information matrices. The information matrices can be found in Appendix A.

5.2.2 Data dictionary with information packs

Some participants need multiple Shared SA requirements from the other participants, and some Shared SA requirements are required from all sea-based participants. In order to make the information matrices clear and ease the readability, the Shared SA requirements were grouped according to their relevance for multiple participants, their similar characteristics, or the participants' needs.

Table 5.5 shows five information packs, and most of the groupings described above. The IP 1 is defined as an IP as the Shared SA requirements are included in AIS signals, while IP 3 and IP 4 are defined with only one Shared SA requirement as it interests all participants. Furthermore, IP 5 is also defined as one Shared SA requirement as it is needed by the manned ships, pleasure crafts and VTS. On the other hand, IP 6 consists of three Shared SA requirements due to their similar characteristics.

Table 5.5: Excerpt of the Data Dictionary where the Shared SA requirements are structured in Information Packs (IPs).

Information Pack	Type of information	SA requirements	Description
IP 1	Static	Call sign	
		Name of ship	
		IMO Number	
		Length and beam	
IP 3		Control mode	Control mode for autonomous ships. i.e. manned, autonomous, remotely controlled
IP 4		Warnings from other ships	Warnings communicated by other ships i.e. special conditions, objects, collision course, close passing
IP 5		Contact information to ROC	
IP 6		Clearance to enter/exit VTS area	
		Clearance to arrive/depart from quay	
		Confirmation of clearance request	

In Table 5.5 it can be seen that the table is divided into the columns *Information Pack*, *Type of information, SA requirements* and *Description*. The first column states the IP number while the second column is used to group specific Shared SA requirements within one IP. For example, in IP 1 the Shared SA requirements are divided into the subgroups *static, dynamic, voyage-related* and *safety-related*, where the static subgroup is presented in Table 5.5. Further, some of the SA requirements are described with a comment on what kind of information it includes, or some special specifications. Table 5.5 only present a selection of the IPs that are created.

5.3 Resulting information matrices

As presented in Section 5.2.1, it was created six information matrices for the different voyage phases and control modes in order to structure the SA requirements needed to obtain a satisfactory Shared SA. The Shared SA requirements presented in the information matrix as Table 5.6 are the ones shared between the participants and not the individual SA requirements, meaning that the participants need more information than presented in the matrix to gain their individual SA. However, it is out of the scope of the thesis.

The information matrix created for the voyage phase Port Arrival/Departure is thoroughly described and analyzed in the following section. There is only one information matrix analyzed as the matrices contain considerable information. The information matrices for the berth, approach, and transit phases can be found in Appendix A alongside the Data dictionary in Appendix B.

Table 5.6: Information matrix of SA requirements for the different participants at Port Arrival/Departure. The definition of the Information Packs (IPs) can be found in Appendix B. IPs marked with asterisk (*) imply the relevant IP contains less SA requirements than presented in the data dictionary for the respective participant.

Task: Port Arrival/Departure

Transmitter Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
Manned ship	X	IP 1, IP 3 IP 4, IP 5	IP 5	IP 1*, IP 4	IP 2, IP 6, IP 7
Autonomous ship	IP 1, IP 4	X	IP 3, IP 11	IP 1*, IP 4	IP 2, IP 6, IP 7
ROC	IP 1, IP 4	IP 1, IP 4, IP 9, IP 12, IP 17	X	IP 1*, IP 4	IP 6, IP 7
Recreational crafts	IP 1, IP 4	IP 1, IP 3, IP 4, IP 5	IP 5	X	IP 2, IP 7
VTS	IP 1, IP 4, IP 16	IP 1, IP 3, IP 4, IP 12, IP 15, IP 16	IP 5	IP 1*, IP 4	X

5.3.1 Manned ships

Table 5.7 displays the second row in Table 5.6 which describes the Shared SA requirements a manned ship needs from autonomous ships, ROC, recreational crafts and VTS to obtain a sufficient Shared SA.

Table 5.7: Excerpt of the first and second row of Table 5.6, displaying the Shared SA requirements needed by the manned ship from the four transmitters.

Task: Port Arrival/Departure

Transmitter / Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
Manned ship	X	IP 1, IP 3 IP 4, IP 5	IP 5	IP 1*, IP 4	IP 2, IP 6, IP 7

Similarly to the Shared SA requirements for autonomous ships presented in Section 5.1.2, it can be seen in Table 5.7 that manned ships require both IP 1 and IP 4 from the sea-based transmitters. In addition, the manned ships should know the control status of the autonomous ships, meaning if the ship is unmanned, manned, or remotely controlled, to know whom and how to contact if needed. This is covered by IP 3. Further, the manned ship needs the contact information to ROC in case incidents or situations the ROC should be informed about.

Whether or not the contact information should be distributed from the autonomous ship or ROC is not specified, as it might change according to the methods and technology used to transmit the information. As a result, IP 5 is placed both in the column for autonomous ship and ROC. Lastly, the manned ship needs the same information from VTS related to weather, clearances, VHF and instructions as autonomous ships presented in Section 5.1.2.

The Shared SA requirements for manned ships and recreational crafts are based on the findings from the HNoMS Helge Ingstad accident report and the GDTA performed by Sharma et al. [16]. The GDTA by Sharma et al. [16] was performed by interviewing ship navigators and SMEs. Therefore, the identified Shared SA requirements are based on knowledge and experiences by navigators.

Even though the Shared SA requirements are identified on a different basis, they are still closely related to the requirements the autonomous ships need. A reason for the similarities is that the three participants are sea-based and need the same information to obtain the Shared SA. The similarities, especially between unmanned and manned ships, result in Shared SA requirements being required from the other sea-based participants and the VTS. Further, the Shared SA requirements from VTS are the same for the unmanned and manned ships as they are the same types of vessels and therefore need the same clearances and information.

Before unmanned autonomous ships start to operate, there must be performed studies and interviews of practices in the areas they will operate. The studies must be performed as there are some areas where it has evolved practices where COLREG have been adapted for navigation in the area [88, p. 4]. In these areas, ROC, OCT or the pilot must know the practices such that the autonomous ship applies to the practices. Not knowing the practices can cause dangerous situations, like all the other participants in the area apply to the defined practice.

Further, in Table 5.7, there is defined that manned ships should know the control mode of the autonomous ship. It should be discussed whether or not that is necessary. Knowing the ship is unmanned can make skeptical navigators perform unwanted maneuvers as they are uncertain of the ship's intentions and are skeptical of autonomous ships. However, knowing the control mode and observing the autonomous ship performing its tasks correctly and in accordance to COLREG or other practices can build trust towards the newly introduced autonomous ships.

5.3.2 Autonomous ships

The third row in Table 5.6 describes which Shared SA requirements an autonomous ship needs from the transmitters; manned ship, ROC, recreational crafts and VTS in order to obtain a satisfactory Shared SA in the environment around port arrival/departure. Table 5.8 shows an excerpt of the row containing the Shared SA requirements needed by autonomous ships.

Table 5.8: Excerpt of the first and third row of Table 5.6, displaying the Shared SA requirements needed by the autonomous ship from the four transmitters.

Task: Port Arrival/Departure

Transmitter / Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
Autonomous ship	IP 1, IP 4	X	IP 3, IP 11	IP 1*, IP 4	IP 2, IP 6, IP 7

As it can be seen from Table 5.8 in combination with the Appendix B the autonomous ships requires IP 1 and IP 4 of both manned ships and recreational crafts. IP 1 includes the same SA requirements as AIS-signals, while IP 4 is defined as warnings communicated from other ships i.e. special conditions, objects, collision course, etc. IP 1 for recreational crafts is marked with asterisk (*) as they might not transmit the same information as manned ships due to different requirements by law as presented in Section 2.1.4.

Furthermore, according to the defined voyage phase presented in Section 2.1 the autonomous ship will be manned by a pilot and OCT. As a result, the autonomous ship needs information about which control mode to sail in and the coordinates of boarding and disembarking of the pilot and OCT which is covered by IP 3 and IP 11. Lastly, even though the autonomous ship is manned, it needs information from the VTS. IP 2, IP 6 and IP 7 covers the information needs of VHF frequency of the VTS area, clearance to arrive/depart from the quay and VTS area, hydrographic measurements and weather conditions.

Autonomous ships have only recently started to operate, meaning that the field is quite new, i.e., Yara Birkeland, which started to operate on April 29th [26]. As the field is quite new, the Shared SA requirements being based on theory and experiments are defined as satisfactory. However, as autonomous ships have started to operate, the information need in both autonomous ships and ROC should be analyzed to validate the identified SA requirements. Such analysis can validate the findings and conclude the need for more Shared SA requirements or disprove the identified Shared SA requirements. Even though new analysis can change the relevant SA requirements Table 5.8 provides a solid basis.

5.3.3 ROC

The fourth row in Table 5.6 is displayed in Table 5.9, and displays the information need for ROC at port arrival/departure. According to the voyage definition presented in Section 2.1 the autonomous ship will be manned with both a pilot and a OCT in the port phase.

Table 5.9: Excerpt of the first and fourth row of Table 5.6, displaying the Shared SA requirements needed by the ROC from the four transmitters.

Task: Port Arrival/Departure

Transmitter Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
ROC	IP 1, IP 4	IP 1, IP 4, IP 9, IP 12, IP 17	X	IP 1*, IP 4	IP 6, IP 7

In Table 5.9 it can be seen that the operator should receive IP 1 and IP 4 from the sea based participants. Further, in the port phase the autonomous ship is manned, meaning that the pilot and OCT are in control of the ship and the operator in ROC is only monitoring the ship. As a result the operator only needs the SA requirements from IP 1 which is defined as *'Dynamic'* in Appendix B.

In addition, the ROC operator needs to know the Estimated Time of Arrival (ETA)/Estimated Time of Departure (ETD) for waypoints, ports and destination, confirmation of pilot and OCT boarding/disembarking, and if the ship is in compliance of COLREG which is covered by IP 9, IP 12 and IP 17. Due to the pilot and OCT being in control of the autonomous ship, the operator only needs to know that the ship is cleared to depart or arrive at quay/VTS area/anchorage site and standing instructions from VTS which are presented in Table 5.9 as IP 6 and IP 7.

Even though the ROC operator is only monitoring the autonomous ship, they still need to have relevant Shared SA requirements available in order to acquire Shared SA to understand the surroundings of the ship. Until the rules and regulations for whom is responsible for manned autonomous ships are determined, the operator should obtain a full Shared SA. Having some information about the environment surrounding the autonomous ship, which is covered by IP 1 and IP 4, can also shorten the time for the operator to get in the loop.

As there are no established rules and regulations regarding autonomous ships, Table 5.9 can contain Shared SA requirements, which will be considered unnecessary, or missing Shared SA requirements which will be considered vital according to the rules. This also applies to the information matrices found in Appendix A for the different voyage phases. Even though the Shared SA requirements might change when there are established new rules, the tables can be a firm base.

5.3.4 Recreational crafts

In the fifth row in Table 5.6 the Shared SA requirements for recreational crafts are presented. The row is presented in Table 5.10 and the Shared SA requirements are analyzed and discussed in the following section. As stated in Section 5.1.3 the Shared SA requirements presented in Table 5.10 are the ones recreational crafts ideally should receive, and not the Shared SA requirements they actually receive.

Table 5.10: Excerpt of the first and fifth row of Table 5.6, displaying the Shared SA requirements needed by the recreational crafts from the four transmitters.

Task: Port Arrival/Departure

Transmitter / Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
Recreational crafts	IP 1, IP 4	IP 1, IP 3, IP 4, IP 5	IP 5	X	IP 2, IP 7

From Table 5.10, it can be seen that recreational crafts ideally should receive the same Shared SA requirements as manned ships, whereas the only difference is IP 6, which recreational crafts do not need as they are not required to ask for clearance to enter the VTS area.

In today's maritime environment, the recreational crafts are mainly navigated based on the Shared SA requirements, which can be inquired visually or auditory and can not acquire most of the Shared SA requirements. Even though they can not obtain the ideal Shared SA requirements now, future technology can be developed based on the information matrices. Moreover, along with the technology, also the laws can develop in the future maritime environment.

5.3.5 VTS

As presented in Section 2.1.5 the main tasks for VTS is to protect the environment and ensure safe and efficient vessel traffic in the VTS area. Table 5.11 displays the row of the Shared SA requirements needed by the VTS to obtain an adequate Shared SA.

Table 5.11: Excerpt of the first and last row of Table 5.6, displaying the Shared SA requirements needed by the VTS from the four transmitters.

Task: Port Arrival/Departure

Transmitter / Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
VTS	IP 1, IP 4, IP 16	IP 1, IP 3, IP 4, IP 12, IP 15, IP 16	IP 5	IP 1*, IP 4	X

To understand the situation in the VTS area it can be seen from Table 5.11 that VTS needs both IP 1 and IP 4 from all the sea based transmitters. In addition, the autonomous ship and manned ship are required to request for permission to enter/exit the VTS area and other specified locations, and to report changes in route plan. This results in the VTS needing information about these requests and changes, which is covered by IP16.

It can be seen that the VTS operator needs the Shared SA requirements describing the control mode, confirmation of pilot or OCT boarding/disembarking, and the full route including waypoints and the ships deviation between current position and planned track. Lastly, as the ROC is only monitoring the voyage in the VTS area, the contact information to ROC is the only Shared SA requirement needed from ROC.

In Section 5.1.4 it was described that the Shared SA requirements for VTS were identified through analyzing guidelines by IMO, NCA's information pages about VTS, and the HNoMS Helge Ingstad accident report, meaning that the Shared SA requirements are based upon highly credible sources. Whilst the IPs which the autonomous ships and manned ships hve in common are stated by law, the extra IPs needed from the autonomous ship are based on information which is thought to be of interest to the VTS operator after performing the literature review. In other words, IP 12, IP 15 and IP 16 should be evaluated when there are established rules for autonomous ships.

Further, it should be clarified whom should transmit IP 12 and IP 16, as the IPs can be transmitted from both ROC and the autonomous ship. In summary, most of the Shared SA requirements presented in Table 5.11 are required by law. The Shared SA requirements which are not required by law, should be revised after laws regarding autonomous ships and ROC are established.

Chapter 6

Present technology supporting Shared SA

The third research question, presented in Chapter 1, regards the present technology used to obtain Shared SA. There are few autonomous ships in the present maritime environment, meaning that the participants mostly consist of manned ships, recreational crafts, and VTS. As presented in Chapter 4 the Shared SA is obtained through the situation assessment process where the Shared SA requirements are gathered from technology and human senses and processed as in the Three Level Model. The results from both Chapters 4 and 5 will be used as the base for the following section.

Yara Birkeland, the world's first autonomous container ship, started to operate on April 29th, 2022 [26]. Yara Birkeland is just one of the first of many autonomous ships which will be included in the future maritime environment. The autonomous ships will vary in their degree of autonomy as presented in Table 2.1, meaning that they can be manned or unmanned. In the present maritime environment, the technology is based upon supporting manned ships, VTS and recreational crafts.

In order to identify which technology should be used to obtain Shared SA when autonomous ships and ROC are included in the maritime environment, the present technology and methods used to obtain Shared SA must be identified. In the following section, the method used for identifying the presently used technology will be described, and the results will be presented and analyzed.

6.1 Method used to identify present technology

The different SA requirements needed by the participants in the various voyage phases are presented in Chapter 5. The following Section will describe the method used to identify the technologies used to present and share the SA requirements needed to obtain a satisfying Shared SA concerning navigation and maneuvering.

6.1.1 Literature review

To identify the technology used in the situation assessment process, a literature review as described in Chapter 3 was performed. In order to identify the technology, the selected literature was analyzed as described in Sections 5.1.1 to 5.1.4, meaning that it was identified technology both directly from the literature but also indirectly through understanding the situations and descriptions of actions. For the identified technology, the items were inserted into lists according to the sources used, similarly to Table 5.1. Table 6.1 displays the sources selected through the literature review and a selection of identified technology used to support the participants' SA. As it can be seen from Table 6.1, the literature consists of descriptions of real situations, guidelines, standards, information pages, rules, and regulations.

Table 6.1: List of sources used to identify present technology used to support Shared SA.

International Conventions, Resolutions and guidelines		
SOLAS [89]	COLREGS [90]	Performance Standards [91]
•ECDIS •VHF •Echo-sounding device	•Navigation lights •Aldis lamp •Bells	•GPS/GLONASS •AIS •Echo-sounding devices
ECDIS Guideline [92]	AIS Guideline [85]	ECDIS/ENC standard [93]
•ECDIS •RCDS	•ARPA •AIS	•ECDIS •ENC
Other literature		
Helge Ingstad [5]	SafeSeaNet [94]	IMO info: AIS[95]
•ARPA •Digital route service	•SafeSeaNet •AIS	•AIS
IMO info: ECDIS [84]	Kystverket [96]	IMO info: LRIT [97]
•ECDIS	•Digital route service	•LRIT

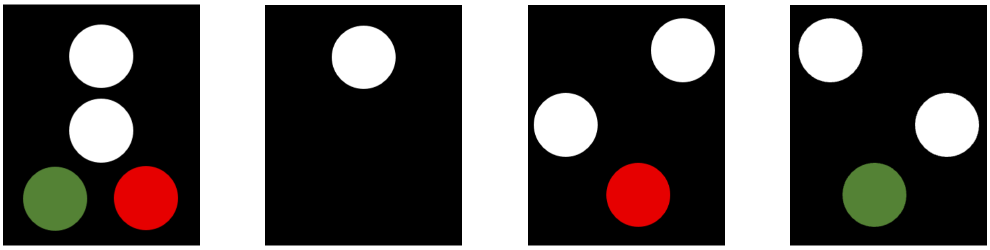
6.1.2 Evaluation of identified present technology

In Table 6.1 there are listed some examples of identified technologies to obtain both SA and Shared SA. To identify the technologies only supporting Shared SA the findings' abilities to support SA or Shared SA were evaluated. The evaluation was performed by searching the literature for descriptions of the usage and which Shared SA requirements the findings presented to the different participants. Some of the questions asked when evaluating the findings are presented below.

- What kind of information is displayed or shared?
- What does the receiver need the information for?
- Does the information support SA or Shared SA?

For example, *Echo-sounding devices* can be used for showing water depth in shallow water. The navigator on a ship will need to know the water depth to locate where it is safe for the ship to sail. In other words, the information is vital for the crew on the ship, but the information will not be shared with other participants. As a result, the *Echo-sounding device* can be viewed as a technology that supports the individual participants' SA but not the Shared SA.

On the other hand, from COLREG [90] *Navigation lights* was identified as technology used in the maritime environment. The navigation lights are used to verify the heading of other boats in the dark. Figure 6.1 demonstrates how the navigational lights can be used to verify the heading of a ship larger than 50 meters. As all participants use the lights to understand the situation, the *Navigational lights* can be viewed as a technology supporting Shared SA.



(a) Ahead **(b)** Astern **(c)** Port **(d)** Starboard

Figure 6.1: Lights seen from ahead, astern, port and starboard in the dark for a ship larger than 50 meters. Adopted from the hand guide for instructors [98].

6.2 Identified present technology

The goal is to identify technology that is used to support Shared SA between the participants when navigating and maneuvering in the present maritime environment. Due to the scope of the thesis, only the technology used to support Shared SA is presented in Table 6.2. In other words, it means that the participants will need information from technologies other than those mentioned in Table 6.2 to gain their individual SA, but that is out of scope.

In order to present the technology found through the method described in Section 6.1, Table 6.2 was created. The table includes the abbreviation of the technology, a description of the abbreviation and the use of the respective technology, and if the technology is required by law. As seen in Table 6.2, there are some footnotes in the column *Required*, which is a result of the rules only applying to ships of specific types, lengths among others. The footnotes will be further described below Table 6.2, and the findings will be described and analyzed.

Table 6.2: Present technology used in the maritime environment to support Shared SA between the different participants. The footnotes are explained beneath the Table, and refers to requirements for specific ships.

Technology	Description	Required
ECDIS	Electronic Chart Display and Information. Used to display Electronic Navigational Charts. Used for route planning, checking, monitoring, and changing routes, alerting for navigational dangers [89, 92].	YES[a]
TSS	Traffic Separation Scheme is a routing measure established by IMO in congested shipping areas. The opposing streams of traffic are separated in traffic lanes to reduce accidents. Can be displayed on ECDIS [90, 99].	YES[b]
Digital Route Service	Reference routes for Norwegian ports. The routes can be downloaded and includes regulations for the respective ports and quays, distances, and the VHF channels for VTS areas [96].	NO
ENC	Electronic Navigational Chart, where the user can zoom in and out. The charts include isolated dangers, depth, safety contours, etc. [84, 92]	YES[a]
RCDS	Used instead of ECDIS where ECS is not available. It does not have the same functionality as ECDIS and must be used along with paper charts [92].	-
RADAR	Radio Detection and Ranging - uses radio waves to detect objects and determine the distance, angle, and velocity. X-band and S-band radar operates in different frequency domains [5, 90].	YES[c]

Technology	Description	Required
ARPA	Automatic Radar Plotting Aid is a radar functionality which can be used to track a vessel. It calculates the course, speed, the closest point of approach (CPA) and time to CPA (TCPA) [5].	YES[d]
GPS/ GLONASS	Global Positioning System is a space-based system for determining position, velocity, and time. GPS/ GLONASS uses different frequencies and operates with different accuracy [91].	YES[e]
AIS	Automatic Identification System is used to identify ships, track objects, and exchange and provide information that can assist the OOW in gaining SA. The data is transmitted from other ships, shore, or satellites. The data can be displayed on ECDIS or individual screens and should be used to supplement the radar [85, 95].	YES[f]
Navigation Lights	Masthead lights, sidelights, and sternlight are used to identify a vessels' position and heading at night, and when there is reduced visibility [5, 90].	YES[g]
Meteorological Sensors	The VTS uses sensors to create an understanding of the weather in their area. Weather forecasts and hydrographic measurements can be shared with those operating in the VTS area.	-
Mobile Phone	Used to communicate with VTS or other vessels [5].	-

Technology	Description	Required
VHF radio	Very High-Frequency radios are widely used. I.e., it can be used to communicate with VTS, and other ships, listen to weather forecasts and coastal radio [5, 89, 91].	YES[c]
NAVTEX	Navigational Telex is an international service for direct printing of navigational and meteorological warnings [89].	YES[c]
SSN	Safe Sea Net is a system to report to all public authorities automatically. Voyages can be inserted and updated in SSN. In addition, the destination port, ETA, ETD, and other required information can be reported [94].	NO
Informational Lights	Lights used to inform other vessels about i.e. dangerous cargo, limited ability to maneuver sailing to/from a Terminal [90].	YES[h]
Whistle, Bell, Gong	Used to signalize special maneuvers and warnings to other vessels, or to attract attention [90].	YES[i]

[a] Applies to newly built passenger ships (≤ 500 GT) and cargo ships (≤ 3 000 GT) on international voyages [84].

[b] Applies to all ships. Ships of length (≥ 20 m), sailing vessels and ships engaged in fishing can use inshore traffic zones [90, p. 22].

[c] Applies to all ships [89, p. 439].

[d] Applies to ships (≤ 10 000 GT) [89, p. 427].

[e] Applies to all ships irrespective of size [89, p. 470].

[f] Applies to ships (≤ 300 GT) engaged in international voyages, ships (≤ 500 GT) not engaged in international waters, all passenger ships. Recreational crafts are not obligated to carry AIS, but can use a Class B system which sends information less frequent[85, p. 1], [89, p. 471].

[g] Applies to all ships. Types and number of navigation lights differ according to the ship length and type of ship [90].

[h] Applies to all ships. Types of lights changes according to what information the lights should present. Some lights can change according to the rules in different countries, while some lights are used due to established practices [90, p. 39-43], [5, p. 58].

[*i*] Applies to all ships of length (≥ 12 m). The types of instruments change according to the vessel size. Ships of length (≤ 12 m) shall carry other instruments/technology making an efficient sound signal[90, p. 45].

Before a ship leaves the quay, the voyage is planned. Table 6.2 presents ECDIS, TSS and Digital Route Service which are used to plan voyages. The Digital Route Service was created in Norway and contains predefined routes which can be downloaded and used in ECDIS. The routes include distances, regulations for the respective ports and VTS areas with their specific VHF channels. By providing predefined routes, the route planning becomes more efficient for mariners; the route is ensured to be safe as it has been evaluated by NCA and information related to a specific route can be communicated to the ships using it [96].

Further, IMO has established traffic lanes in congested shipping areas, called Traffic Separation Scheme (TSS), to reduce the risk of accidents [90]. The traffic lanes work as the land-based traffic lanes and help the participants navigate safely. Figure 6.2 presents how the Traffic Separation Scheme and ENC can be displayed. Lastly, ECDIS can be used for route planning, and change of route, and both the Digital Route Service and TSS can be displayed in ECDIS [92].

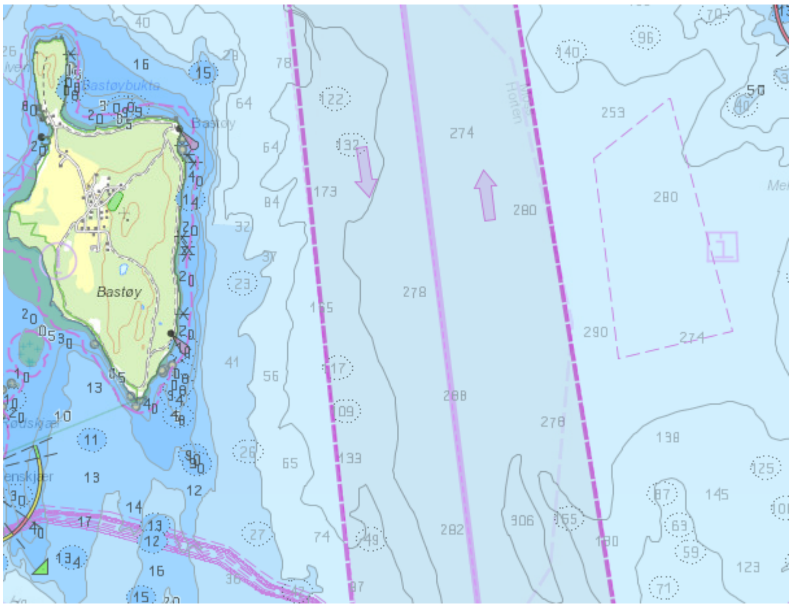


Figure 6.2: Screenshot of Traffic Separation Scheme displayed together with a ENC chart outside Horten, Norway [100].

In Section 5.3 it can be seen that all participants need information about the VHF frequency for VTS area (IP 7) and the traffic situation. The Digital Route Service shares the VHF frequency and special information about the route from VTS, which is used to communicate with VTS and to improve their Shared SA [94].

TSS presents traffic lanes which are used by all participants to improve the safety by ease the to obtain a satisfactory Shared SA, while ECDIS is used to display the information from both technologies. As a result, ECDIS, TSS and Digital Route Service can be seen as technology which supports Shared SA [90].

From Table 6.2 it can be seen that a lot of the identified technology is used to determine the position of the ship itself, and other ships and objects nearby, which also is covered by IP 1 in Section 5.3. ECDIS, ENC, RCDS, RADAR, ARPA and GPS are some of the technologies which are used to support the Shared SA with the position of other participants and navigational hazards.

ECDIS, RCDS, RADAR, and GPS, which are all required by law according to Table 6.2 for larger ships, visually display the position of the ship and ships nearby. In contrast, ARPA which is a radar functionality, can be used to visually and audibly alert the navigators about ships closing up [5]. The information presented through the mentioned technologies is used by the manned ships and VTS to understand the traffic situation and project future dangers and are used as a basis for navigational decisions.

In addition to determining the position, the technology presented in Table 6.2 is also used to identify and verify ships and objects. The AIS is used to obtain information like call signs, types of ships, route plans, types of objects, or sea marks for the ships and objects detected and monitored with the technology described above [5, 85]. At the same time, navigation lights, visualized in Figure 6.1 are used to verify the heading and position of ships at night and in reduced visibility. Combined, the AIS and navigation lights supports the participants in understanding who and what kinds of ships are positioned nearby and their intentions in terms of route and heading. Through covering the Shared SA requirements in IP 1 it is verified that both AIS and navigation lights supports the participantsShared SA.

In the present maritime environment, the VTS is the only shore-based participant. In order to obtain the same Shared SA as the sea-based participants, the VTS must rely on different technology. Technology such as video camera is only used by the VTS to gain SA, and is not presented in Table 6.2 as it does not support Shared SA. Technologies from Table 6.2 that the VTS uses to obtain Shared SA are i.e AIS, RADAR, VHF radio, mobile phones and meteorological sensors. The meteorological sensors are used to understand the weather in their functional area and to gain knowledge about meteorological and hydrographic measures relevant to the sea-based participants [5]. The AIS and RADAR are used to understand the traffic situation, and the VHF radio and mobile phones are used to communicate with ships operating in their area.

As it can be seen from Section 5.3 all participants need information from VTS about weather and hydrographic measurements (IP 2). In contrast to the AIS and RADAR which are used directly to support the participants' Shared SA, the meteorological measurements are used indirectly as the VTS operator first processes the information about weather and hydrographic measures. The VTS and then communicates the information which is important to the participants in their functional area. Even though the technology is not used directly by all participants, they need information presented through the technology, and it is therefore defined as support Shared SA.

In addition to navigational displays, Table 6.2 contains technology which is used by the participants to communicate with each other. There exist multiple different methods to communicate information between participants. The mobile phones and the VHF radio are used to communicate messages, warnings and requests verbally. Through short and concise messages the Shared SA can be supported as the SA requirements covered by IP 2, IP 4, IP 6, IP 7 and IP 16, found in Appendix B, are usually communicated by phone or VHF radio. NAVTEX also communicates the navigational and meteorological warnings in IP 2 and IP 7, but in a written manner, and are therefore also supporting the participants' Shared SA.

Further, the SSN established in Norway can be found to support the Shared SA as it is used to report destination, ETA and ETD of a ship to different public authorities, including the VTS. The VTS operator can use the information to project future traffic situations and standing instructions to ensure a safe voyage for the ship. The Shared SA requirements which SSN can provide are communicated digitally and can be connected to the results in Section 6.2 as the Shared SA requirements are covered by IP 1, which most participants need in all phases of the voyage [94].

Lastly, light and sound signals are used in communication between the sea-based participants. Informational lights are used to communicate, i.e., limited abilities to maneuver, maneuvers, and dangerous or contagious cargo, which is vital information for other participants, as it can affect the navigation of ships nearby. Sound signals are used to signalize maneuvers and warnings to other ships or to attract attention. Consequently, both informational lights and sound signals are technologies used to support the Shared SA for the sea-based participants [90].

To summarize, much technology exists to communicate between the participants, which can be defined as technology used to support Shared SA.

Chapter 7

Future technology supporting Shared SA

Chapter 4 defines SA and Shared SA and described the process of gaining SA and Shared SA which is called situation assessment. In Chapter 5 the SA requirements needed to obtain Shared SA were identified, while the technology used in the present maritime environment to maintain and obtain Shared SA was identified in Chapter 6. The technology presented in Chapter 6 are used by manned ships, recreational crafts and VTS, but the future maritime environment will also include autonomous ships and ROC.

When autonomous ships and ROC are included in the maritime environment, the need for new technology will arise. The technology must satisfy the information need for both autonomous ships and ROC. According to Section 2.1.2, the autonomous ships will operate with different control statuses, from being fully autonomous to remotely controlled. The information matrix for the transit phase presented in Appendix A shows that different control modes result in different information needs. This information need must be covered by new technology or different use of the existing technology.

In the following chapter, new technology and new applications to existing technology which can support the Shared SA when autonomous ships and ROC are present in the maritime environment will be presented. Further, the Shared SA requirements which are not yet covered by the technology will also be identified and discussed.

7.1 Method for identifying future technology

In order to identify new technology which can be used to maintain and obtain Shared SA between manned ships, autonomous ships, recreational crafts, VTS and ROC, there was performed a literature review as descried in Chapter 3. Table 7.1

presents the literature selected through the evaluation of sources. The Table is structured after which participants' Shared SA can be supported by the technology. All literature presented in Table 7.1 was then analyzed and structured as described in Sections 6.1.1 and 6.1.2.

Table 7.1: Sources used to identify new technology used to support the participants Shared SA. The sources are arranged after which participants Shared SA they support.

Remote Operation Center (ROC) and autonomous ships		
Porathe [101]	MUNIN [33]	Ottesen [82]
•Digital twin •QGILD	•Displays for ROC	•Roll/Heave display •Safe Haven •3D recreation
Porathe [102]	Porathe et al. [103]	DNV [32]
•Overview of activities •Weather trends	•Roll/Heave display •IR/Daylight video camera •Safe Haven	•Playback sensor info. •Virtual model •COLREGS compliance
All sea based participants		
Porathe et al. [104]	Kartverket [105]	Porathe et al. [106]
•Route exchange •Alternative routes	Norwegian Pilot Guide	Norwegian Pilot Guide
Porathe et al. [101]	SafeSeaNet [94]	Kystverket [96]
•ECDIS: Intended route	•SafeSeaNet	•Digital Route Service
Kystverket [107]	IMO [108]	
•E-navigation	•E-navigation	

7.2 Method for identifying technology gaps

New technology will be needed when autonomous ships and ROC are included in the maritime environment. The technology used in the future maritime environment is based upon both present and new technology. In order to guarantee that all the Shared SA requirements are covered by both present and future technology the Shared SA requirements covered by the technology presented in Sections 6.2 and 7.3 was marked on a duplicate of the Data Dictionary in Appendix B. The remaining unmarked IPs are not covered by either existing technology or new technology.

7.3 Identified future technology

With the new participants in the maritime environment, there is a need for new technology to ensure that all participants can acquire a satisfactory Shared SA. Table 7.2 presents the identified technology found to be used in the future maritime environment. The Table is arranged after the participants and includes a description of the technology and its use.

Table 7.2: Technology which can be used in the future maritime environment to support Shared SA between the different participants. The technology is arranged after the participants whoseShared SA can be supported by it.

Participant	Technology	Description
ROC/ auto. ship	2D/3D/Virtual model	Visual representation of the situation and the environment surrounding the ship. It should be based on different sensor technologies. Used by the ROC operator to gain an understanding of the conditions [32, 82].
ROC/ auto. ship	Digital Twin	Digital Twin of the autonomous ship. Used to project the ship movement and position when the communication links glitches [101].
ROC/ auto. ship	IR/Daylight video Camera	Used for watch-keeping on autonomous ships. The video camera can transmit both video and still pictures. It can be remotely controlled and used to maneuver the ship from ROC [103].
ROC/ auto. ship	QGILD	Quickly-getting-into-the-loop display or window used to present vital information to the ROC operator. The displayed information should quickly help the operator to gain SA [101].
ROC/ auto. ship	Safe Haven	Safe Haven is defined as the planned position and time slot for the ship according to the voyage plan. It is represented as a rectangular box around the ship and can be used to understand the current situation and performance [82, 103].

Participant	Technology	Description
ROC/ auto. ship	Roll/Heave Display	Pitch/Roll Display used to transmit "ship sense" to ROC operator. Used in the same manner as a flight gyroscope for Roll/Pitch [82, 103].
ALL	Route exchange - Intended routes	Route exchange between all participants. It can be presented on ECDIS. The intended routes can be used to note other ships intentions, or to negotiate in meeting situations where some maneuvers can differ from COLREG [101].
ALL	Alternative routes	Predefined alternative routes are defined during voyage planning. I.e. having to alternative routes around an island. It is used to be prepared for different scenarios such as traffic and weather. It can be used in relation to intended routes, whereas the routes can be changed fairly quickly [104].
ALL	E-navigation	Defined by IMO as "...the harmonized collection, integration, exchange, presentation, and analysis of maritime information on board and ashore by electronic means to enhance berth to berth navigation ..." [108]
	Digital Route Service	Reference routes for Norwegian ports. The routes can be downloaded and includes regulations for the respective ports and quays, distances, and the VHF channels for VTS areas [96].
	NPG	The Norwegian Pilot Guide is a supplement to ENC/paper charts and provides detailed information about the waters, route information, terminals, anchorages etc. It also includes crucial weather and hydrographic information, and can generate a report of point of interest related to the voyage [105, 106].
	SSN	Safe Sea Net is a system to report to all public authorities automatically. Voyages can be inserted and updated in SSN.In addition, the destination port, ETA, ETD, and other required information can be reported [94].

From Table 7.2, it can be seen that more than half of the technology presented is mainly supporting Shared SA for autonomous ships and ROC. Indifferent to the other participants who can use human senses when obtaining Shared SA, the autonomous ships must rely on sensor data, which results in a new technology need. There also exist more technology and systems for communication and control between the autonomous ships and ROC, but the scope of the thesis is to identify the technology which supports Shared SA; other technologies are not displayed.

Ensuring and supporting the ROC operators' Shared SA is one of the main reasons for the new technology need. When the operators are monitoring or controlling the autonomous ship from a remote location, their Shared SA will be based on the information presented to them; therefore, it is vital to design technology to support their Shared SA. In Table 7.2 the technology which can be used to support the ROC operators sea feeling and surroundings (IP1, IP 2, IP 10 and IP 23) are found to be; Digital twins, QGILD, Roll/Heave displays, 2D/3D/Virtual models and IR/Daylight video cameras.

The IR/Daylight cameras combined with a virtual model of the ship and its surroundings can support the ROC operators' Shared SA by visually presenting sensor data. Visualizing information about detected ships, navigational hazards, route changes, weather, or other matters creates a better understanding of the situation than only being presented with the measurements [32, 103]. Also, Digital Twins can be used to better the ROC understandings, as they can predict future position and changes in the surroundings [101]. These technologies can cover the ROC operators information need defined in IP 1, IP 2, IP 13, IP 19 and IP 23.

Unlike IR/Daylight cameras and virtual models, which present the whole situation, the QGILD only displays the bare minimum of information, which is vital to acquire Shared SA quickly [101]. These displays are essential when the ROC operator is monitoring multiple ships, and if the operator gets Out-of-The-Loop (OTL) as the visual displays should not present information in any way that can lead to motion sickness. MUNIN has suggested that the Roll/Heave display can look similar to an artificial horizon display in aviation as presented in Figure 7.1 [82, 103].

Figure 7.1: Artificial horizon display used in aviation can be used to present the ROC operator with the Roll/Heave of the autonomous ship [109].

Another way for the ROC operators to understand the environment surrounding the ship is to comprehend the deviation between the ship's current and planned position, speed, and course. The technology called *Safe Haven* in Table 7.2 can be used to display predefined limitations of the deviation between the planned and current position [82, 103]. The operator can easily understand and follow the ship's progression by illustrating a defined region shaped like a rectangle around the ship as presented in Figure 7.2.

According to the Data Dictionary and information matrices in Appendix B and Appendix A the deviation between the ship's current and planned position, speed and course are covered in the Shared SA requirements in IP 19 and is needed by the ROC operators in the transit phase. In other words, the Safe Haven can be used to support the ROC operators Shared SA and can shorten the time to get in the loop.

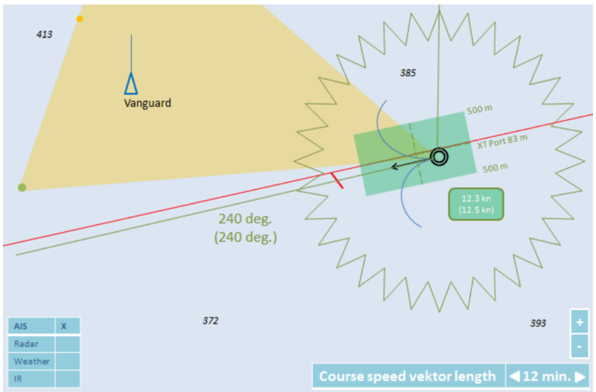


Figure 7.2: Safe Haven presented by MUNIN. The green box presents the planned position of the ship which can be defines as the *Safe Haven* [102].

In addition to supporting the Shared SA of ROC and autonomous ships, Table 7.2 also contains technology which can support the Shared SA for all participants. Of technology relating to route changes Table 7.2 presents route exchange and alternative routes which both can be used in the already existing ECDIS system [104]. In IP 1, found in Appendix B, the waypoints in the route plan are defined as an SA requirement. Besides the information matrix for *'Preparation before voyage'*, all the information matrices presented in Appendix A include IP 1 as information needed by all participants, which displays how vital the information is for the participants to gain a correct Shared SA.

The technology for exchanging intended routes represents a new way to present the intended routes. The system can be used to track another ship's intended route in order to project the future states of the other ships. In addition, the technology can be used to negotiate routes with each other in situations, whereas maneuvers can differ from COLREG. Per the present time, this is usually achieved through the use of VHF radio. However, in a maritime environment where autonomous ships, which cannot use verbal communication, are present, this exchange of intended routes can be practical [101]. Moreover, having predefined routes included in the system for narrow waters and special weather conditions, which can quickly be displayed in ECDIS, can enhance the understanding of other ships' intentions.

Although the technology can improve the Shared SA for the participants when autonomous ships are included in the environment, the technology might have some downsides which should be explored further and will be discussed in Section 8.3

Additionally to the technology specifically related to route changes, Table 7.2 consists of technology which is related to IMO's newest strategy called *E-navigation*. NPG, SSN and the Digital Route Service are direct results of the new strategy [94, 106, 108]. The E-navigation strategy is defined by IMO as "the harmonized collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the maritime environment [108]." In other words, the NPG, SSN and the Digital Route Service are created to enhance the safety and security of navigation for all operating in the maritime environment. The Digital Route Service and SSN are only for use in Norwegian waters and are therefore presented in this chapter regarding new and future technology.

First, the Digital Route Service can be used to prepare before the voyage. The Digital Route Service provides the participants with reference routes that are quality-assured and which include regulations for ports and quays, in addition to distances, safe waypoints, and VTS VHF frequency. Having all this information at hand on the ECDIS eases the navigator's tasks in knowing the routes are safe and whom to contact at different points in the voyage [96]. In comparison to the results found in Chapter 5 the technology can cover both IP 8 and 13 presented in Appendix B, which means that the technology is supporting the participants' Shared SA.

Secondly, the NPG can be used as a supplement to ENC which is presented in Table 6.2. The NPG provides the user with crucial information related to the route, i.e., weather, hydrographical measurements, terminals, and anchorages [105, 106]. Compared to the results presented in Chapter 5, the NPG can encompass IP 2 and IP 13. In the information matrices presented in Appendix A, it can be seen that both IP 2 and IP 13 are transmitted by the VTS and needed by all the other participants in some voyage phases. In other words, even though the NPG can cover some of the VTS tasks as defined now, it can be used to support all participants' Shared SA in the different voyage phases.

Lastly, the SSN is a reporting system where all public authorities can be reported to automatically through one system. Information about the destination port, ETA and ETD can be reported. As described in Section 6.2 the SSN can help the VTS operator in projecting future situations. To summarize, the SSN can be defined as technology which supports the participants' Shared SA [94].

7.4 Identified technology gaps

The results presented in Chapter 5 contain a Data Dictionary where all Shared SA requirements needed by the different participants to maintain and obtain Shared SA during the voyage are identified. Through the method described in Section 7.2, seven IPs were identified to neither be supported by existing nor new technology. Some of the IPs are covered for the participants in the present maritime environment, but not for ROC or autonomous ships, while others are not covered at all. Table 7.3 displays the IPs and the related Shared SA requirements which are not fully covered or covered at all by the technology presented in Sections 6.2 and 7.3.

All IPs in Table 7.3 can be divided into two different categorizes; *autonomous* and *vocal communication*. The *autonomous* category consists of IP 3, IP 5 and IP 17, which represent the information about control mode, contact information to ROC and the autonomous ships' compliance to COLREG. In different to the autonomous category, the *vocal communication* category contains the IPs which are mainly communicated verbally in present maritime environment, meaning IP 4, IP 6, IP 7 and IP 16.

Table 7.3: Overview of Information Pack (IP)s and Shared SA requirements which are only partly covered or not covered at all with the technology presented in Sections 6.2 and 7.3.

Information Pack	Type of information	SA requirements	Description
IP 3		Control mode	Control mode for autonomous ships. I.e. manned, autonomous, remotely controlled.
IP 4		Warnings from other ships	Warnings communicated by other ships i.e special conditions, objects, collision course, close passing.
IP 5		Contact information to ROC	
IP 6		Clearance to enter/exit VTS area	
		Clearance to arrive/ depart from quay	
		Clearance to arrive/ depart from dock/ anchorage site	
		Change in cleared sailing route	
		Confirmation of clearance request	
IP 7		Standing instructions	i.e. navigational instructions, warnings of collision course, rerouting.
IP 16		Request to enter/ exit VTS area	
		Request to arrive/ depart from quay	
		Request to arrive/ depart from dock/ anchorage site	
		Request to change route plan	
IP 17		Compliance of COLREG	COLREG - Convention on the International Regulations for Preventing Collisions at Sea [90]

The autonomous category consists of IP 3 and IP 5 which were found in Chapter 5 to be vital for all participants. For manned ships and VTS both IP 3 and IP, 5 can be implemented in the information gathered through AIS. Nevertheless, for recreational crafts, which usually are not supplied with AIS systems, the information must be presented in another way. For instance, as most people have a mobile phone, an app could be created to notify when there is an autonomous ship nearby. The app can then also include information about contact information to ROC and the ships' intentions. When designing the app or other types of technology, it should focus on supporting the participants' Shared SA. Suppose the existing technology is changed to include IP 3 and IP 5, and new technology is created for displaying the information for recreational crafts. In that case, the Shared SA for all participants will be improved, and the technology gap will be further closed.

While IP 3 and IP 5 are vital for all participants, IP 17 is mostly needed by the ROC operator. IP 17 includes the Shared SA requirement about knowing the autonomous ships' compliance of COLREG. Even though it is mainly the ROC operator who needs the information, it is also of interest to the other participants. Firstly, when introducing autonomous ships, it will be assumed that the ship is navigated in compliance to COLREG. As a result, the ROC operator must monitor the autonomous ship and ensure that it is navigated according to COLREG.

Further, as presented in Section 5.3.1, in some regions, there have been established some unique navigating and maneuvering practices, which the ROC operator must know in order to navigate the autonomous ship following the Shared SA. Because this information is vital for the ROC operator and the other sea-based participants, studies should be performed on how to present the information in the best possible way to ensure Shared SA and prevent information overload for the operator.

IP 6 and IP 16 are included in the vocal communication category and are related to the communication between VTS and sea-based participants operating in the VTS area. The communication consists of requests and clearances regarding the VTS area. Autonomous ships can not communicate vocally as the other participants can. Consequently, established guidelines must clarify if the information should be transmitted directly to the ship or the ROC operator.

When autonomous ships become a more significant part of the maritime environment, transmitting all-vocal information to the ROC operators can lead to work-overload. As the operators most likely will monitor several ships and must transform the information gained through verbal communication into a command, the workload can become extensive. On the other hand, as communication is relatively standardized, it should be possible to create technology that can communicate with autonomous ships directly. For instance, maybe only the communication between autonomous ships and VTS are digitalized, while the other participants can use the VHF radio as before. In that way, only the autonomous ships and VTS must acquire the new technology. Independently of what technology is to be used in the communication, the first step should be to establish the guidelines for communication between VTS, ROC and autonomous ships.

Lastly, IP 5 and IP 7 presented in Table 7.3 are also a part of the vocal communication category. These IPs include standing instructions from VTS and warnings from other sea-based participants. This type of communication is incredibly varied in relation to the communication about request and clearance to enter/exit a VTS area mentioned above. It can vary in who is transmitting it, the situation, content, length of the message, and frequency of receiving messages. Depending on the situation and content of the message, the information communicated verbally can be critical. Some messages can, for instance, contain information about newly arisen navigational hazards, while others can include navigational instructions to prevent a collision.

As the communication of IP 5 and IP 7 can vary in criticality, more thorough studies should be conducted. The studies should focus on which Shared SA requirements is communicated between the participants, if parts of the information can be digitalized, or if this type of communication should be transmitted to the ROC operator.

Chapter 8

Discussion

The thesis aims to create a basis for Shared Situation Awareness (Shared SA) in navigation and maneuvering for participants in the future maritime environment. Chapter 3 presents the search method used to perform literature reviews. Chapter 4 assemble varying literature and theories regarding SA and Shared SA and founds the theoretical basis of the thesis. With the use of the theory form Chapter 4, the methods presented in Chapter 3 and Sections 5.1.1 to 5.1.4 the Shared SA requirements needed by the different participants was identified and structured in information matrices. In Chapters 6 and 7 the identified Shared SA requirements identified in Chapter 5 was used as a basis for the literature review on both existing and new technology which can be used to support the participants Shared SA.

Evaluating the information need with a basis in both theory and technology has formed a foundation that can be used in future work related to the Shared SA for both sea and land-based participants. In the following chapter the methods and results presented in Chapters 3 to 7 will be discussed.

8.1 Literature review

Four literature reviews have been performed, one for each research question, to identify relevant and satisfactory literature. In other words, literature reviews have been an essential part of the thesis. Even though the selection and evaluation process of the literature has been thorough to ensure the quality of the results, there are some downsides to only relying on literature reviews.

Firstly, a challenge with performing a literature review is ensuring the literature's quality. There exists lots of literature, and finding all the literature which is relevant to the subject is impossible. As presented in Chapter 3, lots of the literature was identified through different databases and search words, which means that the identified literature is dependent on the search words. If other search words had been used, the literature which has been identified could have changed. In order to counteract the fact that important literature can have been missed out on, multiple sources were used to cross-check facts. Also, snowballing was used to identify missed literature. Further, to ensure the academic quality of the literature used, databases like *Elsevier* were used to identify peer-reviewed research articles.

Secondly, even though the literature was cross-checked, there exists a risk that some of the literature is outdated and based on varying objectivity. In order to outweigh the amount of outdated and varying objective literature, the literature was thoroughly evaluated as described Section 3.1.2. Nevertheless, as some of these kinds of literature can have passed the evaluation process, all information extracted from all sources was interpreted in a critical manner.

Lastly, where a literature review can be used to portray different angles on a subject, a literature review can only portray the angles which has already been researched. This means that there can be undiscovered perspectives or information that could be important for the thesis. To counteract this, interviews or surveys could have been conducted with seafarers, maritime navigational instructors, or other people with experience in maritime navigation. The results from interviews or surveys could be used to explore new perspectives and to quality assure the identified information and perspectives. However, due to time limitations, there were not performed any interviews or any surveys. In order to make up for the missing interviews, multiple sources were used to cross-check facts. Also, the GDTA performed by [16] and multiple international conventions and other legal documents were used to establish a firm information base.

To summarize, some drawbacks exist to performing literature reviews, which interviews and surveys can counteract. Due to time limitations, interviews and any surveys have not been performed. As a result, different measures have been taken to counteract the fact that the information base is based upon literature reviews, i.e., cross-checking of facts and using international conventions and a GDTA as types of literature.

8.2 Shared SA requirements for maritime navigation

In Chapter 5, both the methods used to identify and structure the Shared SA requirements in information matrices were described, and the resulting information matrices and Data dictionary were presented and analyzed. Due to the information matrices and the Data Dictionary are quite extensive, only one of the six information matrices was presented and discussed in the chapter, while the complete Data Dictionary and all information matrices can be found in Appendices A and B.

The method used to identify the Shared SA requirements and their relation to Shared SA is based on the interpretation of descriptions of conversations and situations, guidelines, GDTA, laws, and work instructions, in a combination of the knowledge revolving Shared SA. The interpretation process can be a source of error itself, as information can easily be misinterpreted. Information can both have been disregarded as its importance and relation to navigational Shared SA has been misinterpreted, or it can have been accepted for the same reasons. As a consequence, it is essential to state that both the Data dictionary and the information matrices can contain inaccuracies in which Shared SA requirements are included, in which phase they are needed, and who needs the different Shared SA requirements.

Further, as some of the sources are based upon Norwegian rules and regulations, like the work descriptions for VTS operators, there can exist Shared SA requirements which is not following all countries' rules and regulations. This should be accounted for when using the Data Dictionary.

As presented above, different measures have been taken to counteract the possible errors, but to quality assure the different SA requirements and information matrices, the results should be presented to a group of people with experience in maritime navigation in order to prove or disprove the results.

8.2.1 Autonomous ships

In different to the Shared SA requirements which concerns all participants, the Shared SA requirements concerning autonomous ships and ROC are purely based on research articles. This itself can be a source of error. Even though the SA requirements have been cross-checked with multiple sources, a study should be performed on the information need for both autonomous ships and ROC, whereas the information matrices can be used as a base.

Moreover, as autonomous ships have just newly started to operate, there have not yet been established rules regarding autonomous ships and ROC. As the rules may require more or less information to be shared between the autonomous ship and ROC, and between autonomous ships, ROC and other participants, the Data Dictionary found in Appendix B can be incomplete.

Whether or not the control mode should be displayed to the other participants is one of the Shared SA requirements which might be affected. As discussed in Section 5.3.1, it can be beneficial to the trust in technology to transmit the control mode in the start phase of autonomous ships. However, it can also lead to unwanted maneuvers from those skeptical of the autonomous ships. Dilemmas like this will probably be accounted for when established rules and regulations exist for both autonomous ships and ROC. Hence, it should be conducted further analysis on the Shared SA requirements needed from and for autonomous ships and ROC.

Lastly, the information matrices presented in Table 5.6 and Appendix A do not only include which type of information the participants should receive but also includes the information each participant should transmit in the different voyage phases. In Section 5.3 only the Shared SA requirements the different participants need to receive from the other participants are analyzed. However, the information matrices like the one in Table 5.6 can also be used to understand the information the participant must transmit to the other participants. It is through this sharing process that the SA requirements changes to Shared SA requirements, as the information is shared between the participants in order to gain a correct Shared SA.

8.3 Present and future technology

Chapters 6 and 7 identify the present and future technology used to display or share the Shared SA requirements to support the participants Shared SA in navigation. There exists lots of systems and technologies used in navigation, but as the scope of the thesis is the Shared SA, Chapters 6 and 7 only provided information and analyzed of technology which supports Shared SA.

The technologies' abilities mainly were discussed concerning the information matrix for port arrival/departure, as the information matrix had been discussed thoroughly in Section 5.3. This was a measure taken to ease the readability and understanding of the importance of the technology. Consequently, there might be other usage areas for the different technology than those described in Sections 6.2, 7.3 and 7.4, whereas some might change according to the different voyage phases.

Unlike the present technology, which has been used for several years, most of the future technology presented in Sections 7.3 and 7.4 has not been tested in the natural maritime environment. To ensure that the technology supports the Shared SA rather than deterring it, the new technology must be tested in the natural maritime environment.

The tests should identify hidden traps or drawbacks as the technology might not support the Shared SA as intended or not benefit all the intended participants. For instance, when Porathe et al. [106] tested the *Intended Routes*, they figured that the VTS operators would not benefit from the technology unless the user could choose which ships to track, as there became too many intended routes to display. The example above demonstrates why the new technology must be adequately tested, as only minor differences can deteriorate a participant's Shared SA.

Lastly, as Section 7.4 presented, the identified present and new technology are not covering all the Shared SA requirements that the different participants need. The identified Shared SA requirements are important to create a good Shared SA. To close the future technology gap, there should be but much effort in designing technology that supports the identified Shared SA requirements.

To summarize, even though the existing technology is satisfactory in the present maritime environment and still can be used in the future maritime environment, there is a need for new technology to ensure that all the Shared SA requirements defined in Chapter 5 for the different participants are covered.

8.4 The future need for Shared SA

Shared SA is already vital in the present maritime environment, as it is one of the barriers which prevents dangerous situations. The present technology which is presented in this thesis is daily in use to support the navigators in their decision making by supporting their Shared SA through displaying and sharing the Shared SA requirements. However, as the HNoMS Helge Ingstad accident has shown, it is still possible to improve the participants' Shared SA even more.

When autonomous ships and their operators in ROCs are included in the maritime environment, the Shared SA becomes even more critical. First, when autonomous ships are included in the environment, it will be expected to decrease the number of accidents at sea. As many situations where human errors can occur within navigation are removed when the ships are autonomous, the focus on Shared SA in situations where human error still can occur must be paid particular attention to. Some examples are the port and approach phases, where the autonomous ship is manually controlled, and the transit phases, where the autonomous ship is remotely controlled. In these situations, the technology must be designed to ensure and support the different participants Shared SA.

Lastly, effort must be put into use Shared SA to create trust in autonomous ships. In the start phase of autonomous ships, some will be skeptical of the automation and the functioning of an autonomous ship. To create a safe environment for all participants, there must be designed technology based on the identified Shared SA requirements to present the autonomous ships Shared SA. For instance, showing the ships' intentions and detected ships, among others.

Chapter 9

Conclusion and Future work

The aim of the thesis was to define Situation Awareness (SA) and Shared Situation Awareness (Shared SA), identify the elements needed to gain Shared SA for manned ships, autonomous ships, recreational crafts, Remote Operation Center (ROC) and Vessel Traffic Service (VTS) in maritime navigation and to identify which present and future technology supports Shared SA.

SA is defined as a product of awareness, where awareness is defined as the perception of all components in the surroundings, the comprehension of the components, and the projection of their future meaning and states. The information needed to gain SA are called SA requirements. In Shared SA, the awareness is shared between different participants and is only based on the SA requirements which are shared between two or more participants, called Shared SA requirements.

In total, 90 different Shared SA requirements related to maritime navigation have been identified and structured in information matrices in accordance with the participants' needs in different voyage phases. A variety of both present and future technology which supports the participants Shared SA through collecting, displaying, or sharing Shared SA requirements have been identified.

When autonomous ships and ROC are entering the maritime environment, Shared SA will become more necessary. There will arise a new information need, and a technology gap as the identified technology cannot cover all the identified Shared SA requirements.

9.1 Future Work

The identified technology and Shared SA requirements are mainly based on theory found through several literature reviews. The following bullet points state verifications of and improvements and recommendations for the identified technology and Shared SA requirements.

- The identified Shared SA requirements should be verified by experienced navigators and VTS operators.
- The identified Shared SA requirements for autonomous ships and ROC should be reviewed after laws regarding autonomous ships and ROC are established.
- There should be performed an analysis similar to the Goal-Directed Task Analysis (GDTA) of the Shared SA requirements for autonomous ships and ROC.
- There should be designed technology which can cover the potential technology gap.
- Future technology should be designed to support the users SA and Shared SA.

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Appendix A

Information Matrices

The Appendix presents the information matrices presented and discussed in Chapter 5.

A.1 Voyage Preparation

The following section presents the information matrix for voyage preparation. The matrix contains the Shared SA requirements needed by all participants in order to securely plan the voyage.

Table A.1: Information matrix of SA requirements for the different participants when preparing before voyage. The definition of the Information Packs (IPs) can be found in Appendix B. IPs marked with asterisk (*) imply the relevant IP contains less SA requirements than presented in the data dictionary for the respective participant.

Task: Preparation before voyage

Transmitter / Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
Manned ship	X	N/A	N/A	N/A	IP 8, IP 13
Autonomous ship	N/A	X	IP 8, IP 9, IP 10, IP 11	N/A	IP 13
ROC	N/A	IP 13	X	N/A	IP 8, IP 13
Recreational crafts	N/A	N/A	N/A	X	IP 13
VTS	IP 9	N/A	IP 9, IP 11	N/A	X

A.2 Port Arrival/Departure

The following section presents the information matrix for Port Arrival/Departure. The matrix contains the Shared SA requirements needed by all participants in the Port Arrival/Departure phase

Table A.2: Information matrix of SA requirements for the different participants at Port Arrival/Departure. The definition of the Information Packs (IPs) can be found in Appendix B. IPs marked with asterisk (*) imply the relevant IP contains less SA requirements than presented in the data dictionary for the respective participant.

Task: Port Arrival/Departure

Transmitter / Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
Manned ship	X	IP 1, IP 3 IP 4, IP 5	IP 5	IP 1*, IP 4	IP 2, IP 6, IP 7
Autonomous ship	IP 1, IP 4	X	IP 3, IP 11	IP 1*, IP 4	IP 2, IP 6, IP 7
ROC	IP 1, IP 4	IP 1, IP 4, IP 9, IP 12, IP 17	X	IP 1*, IP 4	IP 6, IP 7
Recreational crafts	IP 1, IP 4	IP 1, IP 3, IP 4, IP 5	IP 5	X	IP 2, IP 7
VTS	IP 1, IP 4, IP 16	IP 1, IP 3, IP 4, IP 12, IP 15, IP 16	IP 5	IP 1*, IP 4	X

A.3 Approach

The following section presents the information matrix for the approach phase. The matrix contains the Shared SA requirements needed by all participants in the approach phase.

Table A.3: Information matrix of SA requirements for the different participants in the approach phase. The definition of the Information Packs (IPs) can be found in Appendix B. IPs marked with asterisk (*) imply the relevant IP contains less SA requirements than presented in the data dictionary for the respective participant.

Task: Approach with OTC

Transmitter / Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
Manned ship	X	IP 1, IP 3, IP 4, IP 5	IP 5	IP 1*, IP 4	IP 7
Autonomous ship	IP 1, IP 4	X	IP 3, IP 11, IP 24	IP 1*, IP 4	IP 2, IP 7
ROC	IP 1	IP 1, IP 9, IP 12, IP 17	X	IP 1*, IP 4	IP 7
Recreational crafts	IP 1	IP 1	IP 5	X	IP 7
VTS	IP 1, IP 4, IP 16	IP 1, IP 3, IP 4, IP 12, IP 15, IP 16	IP 5	IP 1*, IP 4	X

A.4 Transit

The following section presents the three information matrices for the transit phase. There is one matrix for each of the control modes *'Autonomous Control', 'Indirect Remote Control '* and *'Direct Remote Control'*. The matrices contains the Shared SA requirements needed by all participants in the different control modes in the transit phase.

Table A.4: Information matrix of SA requirements for the different participants in the transit phase in 'autonomous control'. The definition of the Information Packs (IPs) can be found in Appendix B. IPs marked with asterisk (*) imply the relevant IP contains less SA requirements than presented in the data dictionary for the respective participant.

Task: Transit - Autonomous Control

Transmitter / Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
Manned ship	X	IP 1, IP 3, IP 4, IP 5	IP 5	IP 1*, IP 4	N/A
Autonomous ship	IP 1, IP 4	X	IP 18, IP 24	IP 1*, IP 4	N/A
ROC	IP 1, IP 4	IP 1, IP 9 IP 17, IP 19	X	IP 1*, IP 4	N/A
Recreational crafts	IP 1, IP 4	IP 1, IP 4	IP 5	X	N/A
VTS	N/A	N/A	N/A	N/A	X

Table A.5: Information matrix of SA requirements for the different participants in the transit phase in ’indirect remote control’. The definition of the Information Packs (IPs) can be found in Appendix B. IPs marked with asterisk (*) imply the relevant IP contains less SA requirements than presented in the data dictionary for the respective participant.

Task: Transit - Indirect Remote Control

Transmitter Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
Manned ship	X	IP 1, IP 3, IP 4, IP 5	IP 5	IP 1*, IP 4	N/A
Autonomous ship	IP 1, IP 4	X	IP 18, IP 20 IP 24	IP 1*, IP 4	N/A
ROC	IP 1, IP 4	IP 1-4, IP 9, IP 17, IP 19, IP 21	X	IP 1*, IP 4	N/A
Recreational crafts	IP 1, IP 4	IP 1, IP 4	IP 5	X	N/A
VTS	N/A	N/A	N/A	N/A	X

Table A.6: Information matrix of SA requirements for the different participants in the transit phase in ’direct remote control’. The definition of the Information Packs (IPs) can be found in Appendix B. IPs marked with asterisk (*) imply the relevant IP contains less SA requirements than presented in the data dictionary for the respective participant.

Task: Transit - Direct Remote Control

Transmitter Receiver	Manned ship	Autonomous ship	ROC	Recreational crafts	VTS
Manned ship	X	IP 1, IP 3, IP 4, IP 5	IP 5	IP 1*, IP 4	N/A
Autonomous ship	IP 1, IP 4	X	IP 22, IP 24	IP 1*, IP 4	N/A
ROC	IP 1, IP 4	IP 1-4, IP 9-10, IP 13, IP 17, IP 19, IP 22-23	X	IP 1*, IP 4	N/A
Recreational crafts	IP 1, IP 4	IP 1, IP 4	IP 5	X	N/A
VTS	N/A	N/A	N/A	N/A	X

Appendix B

Data Dictionary

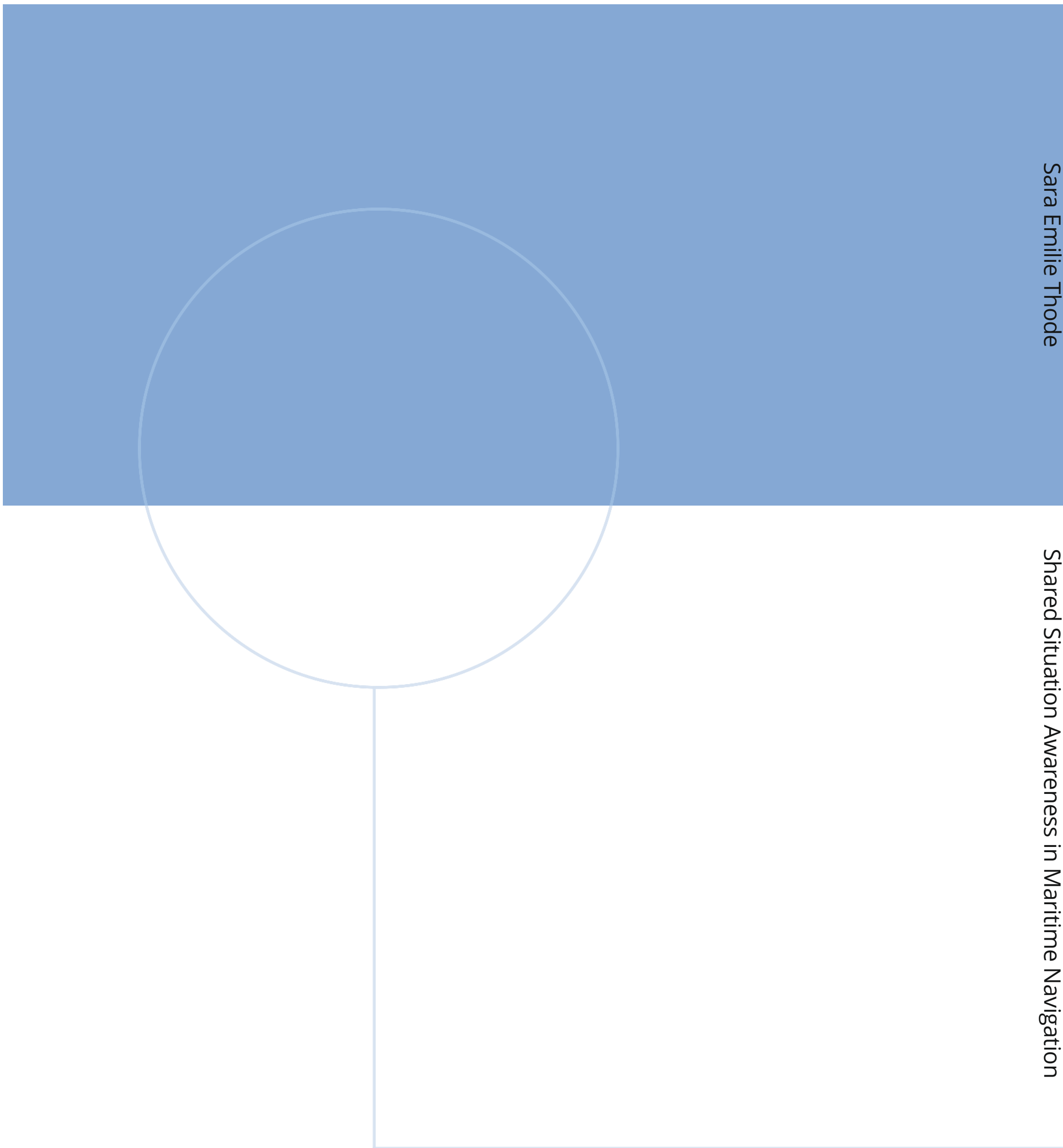
The Appendix presents the Shared SA requirements and the respective Information Packs (IPs) identified in Chapter 5. The IPs are used to describe the information need for the participants and are used to analyze present and future technology which shares or presents the Shared SA requirements to the participants.

Data Dictionary

IP = Information pack	Type of information	SA requirements	Description
IP 1	Static	Marine Mobile Service Identity (MMSI)	
		Call sign	
		Name of ship	
		IMO Number	
		Length and beam	
		Type of ship	
		Location of electronic position fixing system (EPFS) antenna	
	Dynamic	Ship's position with accuracy indication and integrity status	
		Position Time stamp in UTC	
		Course over ground (COG)	
		Speed over ground (SOG)	
		Heading	
		Navigational status (manually entered)	i.e. underway by engines, at anchor, not under command, restricted in ability to manouvre, moores, constrained by graught, aground, engaged in fishin, underway bu sail
		Rate of turn (ROT)	
		Navigation lights	Side and sternlights regulated by COLREG. Lights used for signalizing dangerous cargo, approach/leaving terminal or to signalize special conditions
	Voyage-related	Ship's draught	
		Type of hazardous cargo (type)	DG - Dangerous goods, HS - Harmful Substances, MP - Marine Pollutants
		Destination and ETA	
		Route plan (waypoints)	
	Safety-related	Short safety-related messages	
IP 2	Weather conditions	Visibility	
		Temperature	
		Sea Temperature	
		Wind Speed	
		Wind Direction	
		Air pressure	
	Hydrographic measurements	Current/Tidal Stream Speed	
		Current/Tidal Stream Directions	
		Range of Tides	
		Height of Waves	

		Sea state	i.e. calm, rough, high.
IP 3		Control status	Control mode for an unmanned ship. I.e. manned, autonomous, remotly controlles
IP 4		Warnings from other ships	Warnings communicated by other ships i.e special conditions, objects, colission course, close passing
IP 5		Contact information to ROC	
IP 6		Clerance to enter/exit VTS area	
		Clerance to arrive/depart from quay	
		Clearance to arrive/depart from dock/anchorage site	
		Change in cleared sailing route	
		Confirmation of clearance request message	
IP 7		VHF frequency for VTS area	
		Standing instructions	i.e. navigational instructions, warnings of collision course, rerouting
		Traffic situation	
IP 8		Calling ID for Ports and VTS	
		Planned route	Map with planned route to upload in the navigational system for the unmanned ship from the ROC
IP 9		ETA	For waypoints, ports, end destination
		ETD	For waypoints, ports, start destination
IP 10		Distance to waypoints	
		Planned speed for each leg	
		Traffic Separation Scheme (TSS)	
		Time line	
		Weather/hydrographical forcasts	Forcasts of the SA requirements from IP 2
IP 11		ETA/ETD of pilot	
		Coordinates for pilot boarding/disembarking	
		Coordinates for OCT boarding/disembarking	
IP 12		Confirmation of pilot/OCT boarding/disembarking	
IP 13		Location of navigational hazards	
		NoGo zones	
		Ancorage areas	
IP 14		Confirmation of upload	
		Diagnostic report of Navigation and Manouvering systems	
IP 15		Planned route	Path of the route, not only including waypoints as IP 1
		Deviation between current position and planned position (XTE)	
		Request to enter/exit VTS area	

IP 16		Request to arrive/depart from quay	
		Request to arrive/depart from dock/anchorage site	
		Request to change route plan	
IP 17		Compliance of COLREG	COLREG - Convention on the International Regulations for Preventing Collisions at Sea, 41 rules
IP 18		Periodic updates of plans	i.e. route, timelines, coordinates for boarding/disembarking of OCT/pilot
IP 19		Current distance to neasest obstacles/vessels	
		Trend of detections/abnormal situations	
		Projected position	
		Projected relative separation	
		Deviation between current position and planned position	
		Deviation between current speed and planned speed	
		Deviation between planned course and course made good	
IP 20		Updated route plan	
		Updated waypoints	
		Updated speed for each leg	
		Uptated treshold values	
		Special weather conditions and hydrographical measurements	Includes all measurements described in IP 2
IP 21		Confirmation on received updates	
		Confirmation on updated plans or threshold values	
IP 22		Actuator control	
IP 23		Gyro heading	
		Magnetic heading	
		Location of navigation hazards	
		Projected ETA of waypoints	
		Roll/Pitch	
		Impact of Weather/hydrographical conditions	Including all SA requirements from IP 2
		Weather/hydrographical forcasts	Forcasts of the SA requirements from IP 2



Sara Emilie Thode

Shared Situation Awareness in Maritime Navigation

NTNU
Norwegian University of
Science and Technology