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Evaluating design requirements for a remote-control system

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Abstract

Remote-control of an unmanned surface vessel is an essential part of unmanned maritime operations. Remote-controlled vessel operations are one of the first and crucial steps towards the future of unmanned and autonomous maritime operations.

The objective of the thesis is to establish user-centred design requirements for a remote-control system. The aim is to understand the phenomena of remote-controlled operations and to determine how different standards, guidelines, best practises and human factors regulate, guide or frame them.

The thesis includes the examining of system engineering process, requirement handling, human factors, situation awareness and decision-making as well as standards, guidelines, design principles and codes of practise. The research problem and questions are examined mainly by compiling and analysing sources using literature research methods from the user's point of view.

An essential part of the study is the cognitive Goal-Directed Task Analysis (GDTA) focused on the remote operators´ navigation tasks. The purpose of the analysis is to determine remote the operators´ information, decision-making and situation awareness requirements. The results include some design requirements for a remote-control system based on the operators´ needs.

Language: English

Key words: Remote-control, operation management, navigation, goal, task analysis, situation awareness, decision-making and requirements.

OPINNÄYTETYÖ

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Tiivistelmä

Miehittämättömän pinta-aluksen kauko-ohjaus on olennainen osa autonomisia merioperaatioita. Kauko-ohjattu alustoiminta on yksi ensimmäisistä ja keskeisistä askeleista kohti miehittämättömän ja autonomisen merenkulun tulevaisuutta.

Opinnäytetyön tavoitteena on määrittää vaatimuksia kauko-ohjausjärjestelmän suunnittelulle ja kehittämiselle käyttäjälähtöisen suunnittelun näkökulmasta. Tavoitteena on ymmärtää kauko-ohjattujen operaatioiden ilmiöitä ja selvittää, miten erilaiset standardit, ohjeet, parhaat käytännöt ja inhimilliset tekijät (human factors) ohjaavat tai kehystävät niitä.

Opinnäytetyö sisältää järjestelmän suunnitteluprosessin, vaatimustenhallinnan, inhimillisten tekijöiden, tilannetietoisuuden ja päätöksenteon sekä standardien, ohjeiden, suunnitteluperiaatteiden ja käytännesääntöjen tutkimusta. Tutkimusongelmaa ja kysymyksiä tarkastellaan kirjallisuustutkimuksen menetelmillä sekä kokoamalla ja analysoimalla lähteitä käyttäjän näkökulmasta.

Tutkimuksen keskeinen osa on etänavigointitehtävään keskittyvä kognitiivinen tavoitekeskeinen tehtäväanalyysi (GDTA). Analyysi on laadittu kauko-ohjausjärjestelmän operaattorin tieto-, päätöksenteko- ja tilannetietoisuusvaatimusten selvittämiseksi. Tulokset sisältävät kauko-ohjausjärjestelmän suunnitteluvaatimuksia, jotka perustuvat operaattorin tarpeisiin.

Kieli: Englanti

Avainsanat: Kauko-ohjaus, tehtävänhallinta, navigointi, tavoite, tehtäväanalyysi, informaatio, tilannetietoisuus, päätöksenteko ja vaatimukset.

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Table of contents

Introduction 1

1.1 Background and problem formulation 1

1.2 Objective and delimitation 4

1.3 Research problem and questions 5

2 Conceptual framework 5

2.1 System design and development process 6

2.1.1 Requirement management 8

2.1.2 Development of system-level technical requirements 9

2.2 Human factors engineering 9

2.2.1 Human system interaction 10

2.2.2 Situation awareness 11

2.2.3 Decision-making 16

2.2.4 Command and control 18

2.2.5 Task analysis 19

2.3 Autonomous and unmanned ships 20

2.4 Levels of autonomy and control 23

3 Research Methodology 27

4 Requirements, guidelines and functions for remote-control centre 30

4.1 Remote-control centre 30

4.2 Standards and guidelines regarding remote-control centre 33

4.3 Functions of remote-control centre 35

4.4 Navigation 37

4.5 Monitoring and controlling 39

4.5.1 Monitoring 40

4.5.2 Controlling 41

4.6 Summary 43

5 Human factors guidelines and principles 44

5.1 Design principles that support situation awareness 45

5.2 Guidelines for human centred system design 47

5.3 Summary 49

6 Operated systems 50

6.1 Operation management system 50

6.2 Navigation system 52

6.2.1 System description 52

6.2.2 Example of an integrated bridge system 54

6.2.3 Unmanned Vessel´s Navigation System 55
6.3 Unmanned surface vessel systems 56
6.3.1 Unmanned maritime surface vessels 56
6.3.2 Vessel systems 57
6.3.3 Examples of unmanned surface vessels 58
6.4 Summary 61
7 The Goal-Directed Task Analysis of the remote operators´ navigation tasks 62
7.1 Framework scenario 64
7.2 The remote operators´ overall goal 66
7.3 Sub-level goals 67
7.3.1 A safe and efficient passage plan is established 68
7.3.2 Pre-departure procedures are completed 70
7.3.3 Passage is executed safely, legally and efficiently 72
7.3.4 Post-mission analysis is conducted, documented and briefed 75
7.4 Results of the Goal-Directed Task Analysis 76
8 Conclusions, discussion and critical review 77
8.1 Results of the thesis 80
8.2 Future research 81
9 Bibliography 82
List of tables 89
List of figures 90
Appendix 1 The Goal-Directed Task Analysis of the remote operators´ navigation tasks 92
Appendix 2 The results of the GDTA, information, decisions and requirements for the remote-control system 98
Appendix 3 Interview questions and workshop topics 104
Appendix 4 Definitions and explanations 105

Introduction

1.1 Background and problem formulation

Autonomous and remotely controlled shipping has developed quite rapidly during last ten years. One aim of autonomous and unmanned shipping is to make shipping safer and more cost-efficient. Industrial projects are trying to pilot the implementation of concepts and technologies of autonomous and remotely controlled shipping all around the world (Det Norske Veritas (DNV), 2018a, p. 7). Development of Maritime Autonomous Ship Systems (MASS) has continued during recent years and more unmanned systems are becoming operational all the time. Autonomous ship systems come in many different sizes and operational capabilities, which all have different requirements for design, development and operations. MASS include development elements of robotics and artificial intelligence systems. (Maritime UK, 2021, p. 4).

There has been an increasing interest to design and develop autonomous maritime systems for some years. The rising need for transportation services and requirements for higher level of safety have been the contributing factors for autopilots of vessels and vehicle systems. Autonomous surface vessels are used for different applications containing environmental and geographical survey, acquisition of weather information, search and rescue, research platforms and transport. Autonomous systems usually consists of three software parts, which are navigation, guidance and control (NGC) systems. (Zheng et al., 2014, p. 8812).

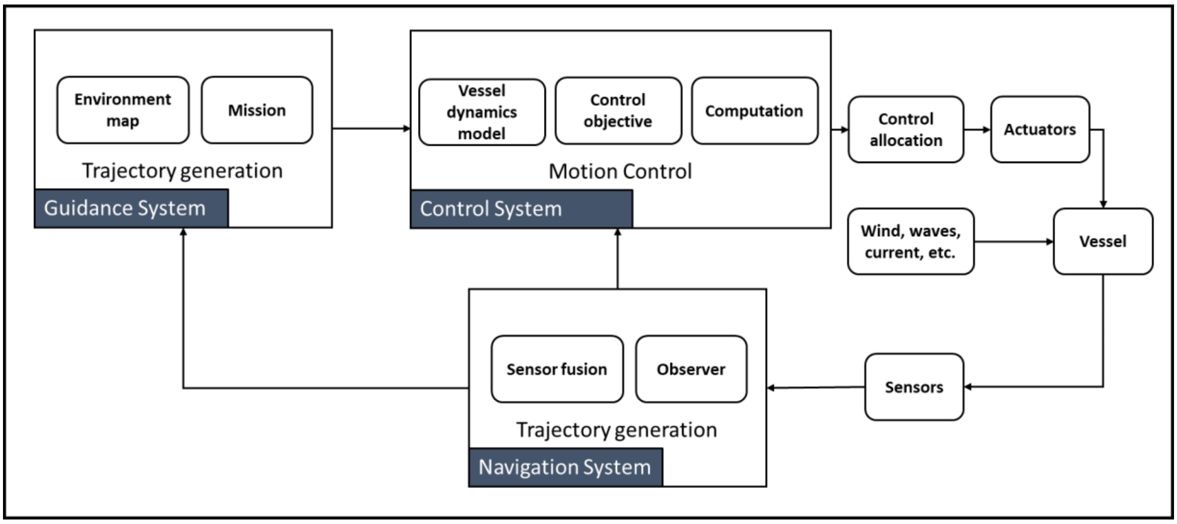

Figure 1: Diagram of an NGC system for autonomous marine surface vehicles (Zheng et al., 2014, p. 8812).

Many researchers, designers and developers are increasingly interested in autonomous and unmanned operations. The interest of conducting various kind of operations on land, at sea and in the air has grown dramatically during recent years based on technological development and improvements of data processing, and sensor technology. Unmanned maritime operations that are conducted autonomously or remotely from another vessel or ashore seems to be interesting because of the possibilities to reduce crew on-board ships and because of technical, safety, security and environmental point of views.

Researching and defining unmanned and remote operations seem to be challenging since there are only few standards, agreed procedures or codes of conduct to define and regulate area of unmanned operations. Autonomous and remote operation of vessels is an immature field and new ideas and technical solutions arise frequently. This is probably the reason why it may not be feasible to establish detailed rules and regulations at the moment. (DNV, 2018a, p. 7.). Standards and guidelines typically aim to improve safety and give framework and guidance for implementation of new technologies regarding remotely operated and autonomous shipping. International Maritime Organisation (IMO) has approved Interim Guidelines for Maritime Autonomous Surface Ships trials and IMO Outcome of the regulatory Scoping Exercise for the use of Maritime Autonomous Surface Ships. Publications from classification companies such as Bureau Veritas (BV), Det Norske Veritas GL (DNV), Lloyd's Register (LR) and Maritime UK Industry Conduct Principles and Practice regulate, guide and advise design and development of unmanned surface vessel systems and remote-control.

European Defence Agency´s (EDA) Best Practice Guidance for Unmanned Maritime Systems (SARUMS 2018) provides a number of various guidelines and best practises for unmanned maritime systems´ handling, operations, design and regulations. EDA (2018) defines the concept of Unmanned Maritime Systems (UMS) as all systems, associated components and subsystems needed to operate these systems with control system, vehicle, logistics and interacting personnel (European Defence Agency (EDA), 2018, p. 3-4).

Maritime Unmanned Navigation through Intelligence in Networks (MUNIN 2015) project investigates feasibility of unmanned ships and aims to develop and verify a concept for an autonomous ship. Some of the driving factors for the project are based on the reasons that the working environment on-board may not be attractive for young people in the future and may form a risk of shortage of seafarers. There is also an increasing need to reduce transportation costs and emissions and increase safety in shipping. In the MUNIN (2015) project scenario, a ship is manned when leaving and entering the harbour and unmanned during open sea operations. During unmanned operations the ship is controlled by an automatic system that uses on-board sensors to make collision avoidance manoeuvres and is monitored by a remote-control centre that can take over control of the ship if automatic system fails. (European Commission (EC), 2015, p. 1-5). Aforementioned publications are selected as sources for this thesis regarding standards, guidelines and best practises.

Autonomous and remote operations in commercial shipping tends to concentrate mainly on navigating, steering a commercial ship from one destination to another, from a remote location. Remote and autonomous operations can also include customised payload operations that are relevant to the current design and development programs in the military. An increasing tendency in the design and development of operation management systems seems to be the requirement to design and develop flexible and highly integrated systems or systems of systems that are capable of managing patrolling, intelligence, surveillance and reconnaissance or warfare operations. Operations in the context of this thesis mean that they are conducted on-board a manned mother ship using operation management system for remotely controlling unmanned surface vessels or in some cases unmanned aerial vehicles and sub-surface vehicles or a combination of them. This requires a lot from the systems and the operators such as adequate, relevant, reliable and time-precise information from a ship´s own systems, controlled systems, and the operating environment as well as high level of situation awareness and advanced interaction with human beings and machines.

The development of remotely operated or autonomous aircraft and vessels seems to have been fastest in the military so far. The unmanned aerial vehicles (UAV) or drones have been in operational use in the United States and many other capable military forces for many years and that capability seems to have recently spread out to the world to become common and usual. In the maritime branch, the development of the unmanned surface vessels (USV) has increased especially after 2010. Currently, there are several operationally ready systems and ongoing research, design and development projects. In the military field, countries such as USA, China, United Kingdom, Germany and Israel have developed and tested unmanned patrol vessels and autonomous sub-merged vehicles for some years. Most of them are still in development or testing phases and therefore not in operational use or at least are not publicly known to have such a status. Some small unmanned surface vessel systems are already in operative use in the navies around the world. One example is the Arcims system that is in service in the Royal Navy in the United Kingdom. Arcims aims to provide flexible capability for the detection and classification of submarines, mines and surface platforms. Detection is achieved by the integration of sensor packages into an intelligent platform allowing fully autonomous, remote-controlled or manned operations. (ATLAS ELEKTRONIK U.K. (AEUK), 2021).

In general, surface or sub-surface vessels can be manned, remotely operated or autonomous. In practise this classification is not as clear and simple as can be seen in the definitions and levels of autonomy. One thing that is common to all vessel operations is situation awareness. Situation awareness is one of the key factors in autonomous and unmanned maritime operations and when monitoring and controlling vessels from a remote-control centre. Safe remote-controlled operations are based on adequate and real-time situation awareness provided by sensor data and operation systems. The operators´ situation awareness seems to be one of the most interesting studying branches in the field of the autonomy at the moment, especially when examining what the effects of unmanned and remote operations to the human operators´ situation awareness are. One of the important points of this thesis is the remote operators´ situation awareness requirements.

1.2 Objective and delimitation

Evaluating design requirements for a remote-control system of an unmanned surface vessel refers to remote maritime operations that can be conducted using a remote-control system that utilises an operation management system (OMS) as a host system and main tool for planning and executing operations. The remote-control system can be located on-board a mothership or ashore, for example in an office, vehicle or containerised facility.

The objective of the thesis is to establish user-centred design requirements for a remote-control system. The aim is to understand the phenomena of remote-controlled operations and determine how different standards, guidelines, best practises and human factors regulate guide or frame them. The thesis includes the examining of system engineering process, requirement handling, human factors, situation awareness and decision-making as well as standards, guidelines, design principles and codes of practise. The research problem and questions are examined mainly by compiling and analysing sources using literature research methods from the user's point of view.

An essential part of the thesis is the cognitive Goal-Directed Task Analysis (GDTA) focused on the remote operators´ navigation tasks. The purpose of the analysis is to determine the remote operators´ information, decision-making and situational awareness requirements. The GDTA maps what information the remote-control system operators’ need and what kind of decisions, choices and checks the operators have to make in remote navigation tasks in order to achieve their goals. Levels of situation awareness are analysed regarding decision-making requirements. Some requirements for the remote-control system design are derived based on information, decision-making and situation awareness requirements.

The task analysis concentrates on a remote-control system operator´s navigation tasks and does not cover an operator team´s situation awareness, task allocation or workload. Payload operations are classified as restricted and are not presented in this thesis. Data transfer capabilities, means and challenges including information and cyber security requirements are not included in the scope of this research. Regarding data communication system between an USV and a control system, only those parts that affect the design of the control system itself are considered, while the actual data communication is outside the study area.

1.3 Research problem and questions

The research problem is to determine what the design requirements for remote-control system from the user-centred perspective in the context of this thesis are. Research questions that the thesis aims to answer are as follows:

1. What is a remote-control centre? Chapter 4 answers the first research question.
2. What are the remotely operated systems? This question is answered in Chapter 6.
3. What are the remote-control system operators´ goals and information, decision-making and situation awareness requirements in navigation tasks? These questions are answered in Chapter seven as well as in Appendices 1 and 2.
4. What are requirements for a remote-control system from the user-centred perspective? Chapters 4 and 5 as well as Appendix 2 answers this question.

2 Conceptual framework

A conceptual framework of the thesis contains system design and development, requirement handling and human factor engineering. Additionally, key elements of situation awareness, human system interaction, remote-controlled operations, levels of autonomy and the operators´ role are included in the concept framework.

2.1 System design and development process

According to MITRE Corporation (2021), system design is a process of defining the components, modules, interfaces and data for a system to satisfy pre-defined requirements. System development is a process of creating or changing systems, processes, practices, models and methodologies. National Aeronautics and Space Administration (NASA) uses system design processes to define, generate and baseline technical requirements, decompose the requirements into logical and behavioural models and convert the technical requirements into a design solution that will satisfy stakeholder expectations.

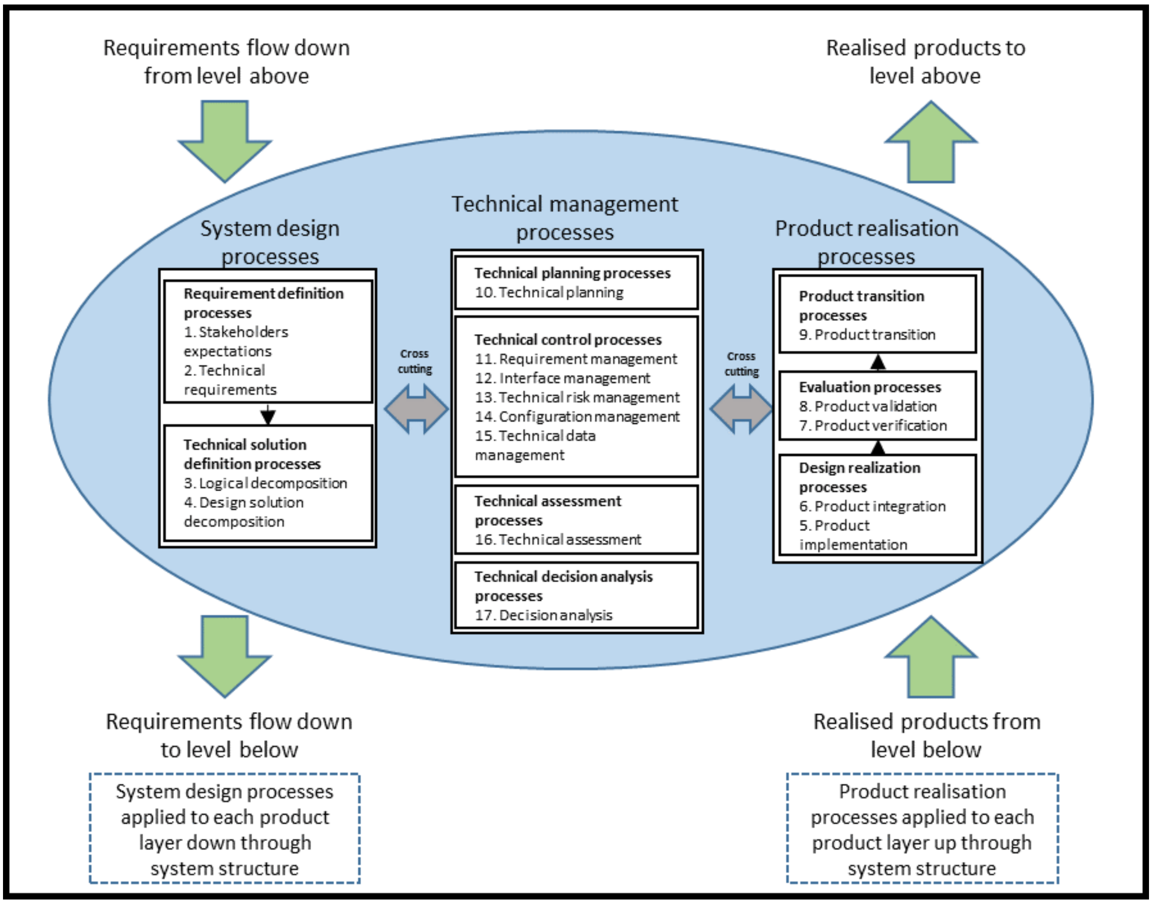

Figure 2: NASA System Engineering engine (NASA, 2020, p. 6).

According to Lee et al. (2017), systematic design processes include phases for product analysis, design and production. All phases include several steps that aim to understand customer´s or user’s needs, design and develop the system and evaluate and test how well the system fulfils pre-set requirements. System engineering process is an iterative process that returns back to understanding the user's needs. One example of the system engineering process in so called Vee process. The Vee process is usually used in the design of large or high-risk systems in which evaluation, verification, validation and documentation are critical. The Vee model starts the process with a general system description and functional description of the system. It includes phases to analyse and define design requirements, which are formulated to detailed system requirements in later a phase of the process. Integrating human factors into the process in the early phase is important.

Comprehensive task analysis typically provides accurate requirements and suits the Vee model probably the best; however, it requires a lot of resources and may take a long time to be completed. The primary principle in human factors engineering is to focus design processes on the human operators, making them human centred processes. (Lee et al., 2017, p. 22). The content of this thesis is part of typical system development process phase of requirement analysis and specification before the preliminary design phase is started.

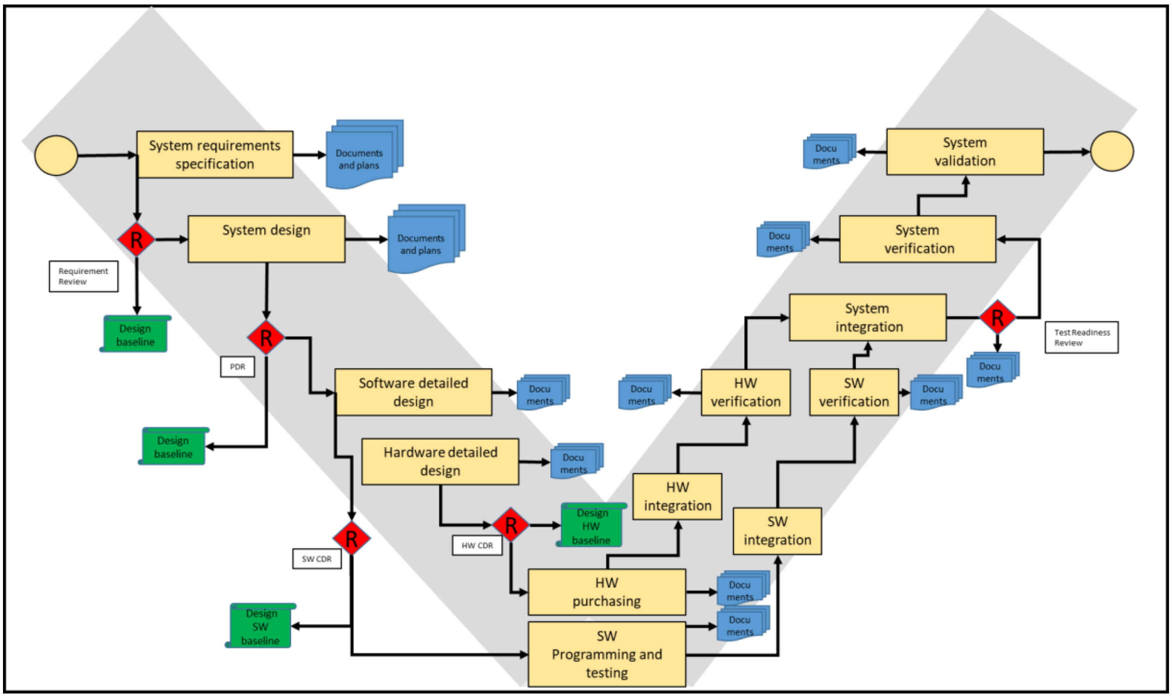

Figure 3: A system development process where system requirements are defined, analysed and specified prior to system requirement review (Applied from Lee et al., 2017, p. 21 and ATLAS ELEKTRONIK Finland (AEFI) process chart).

According to Endsley and Jones (2011), requirements analysis is one of the most important phases of the design process. Ambiguous project objectives are transformed into more detailed requirements in requirements analysis phase. Requirement analysis usually includes establishing an operational concept together with analysing environmental conditions, user characteristics and other operational requirements. Operational requirements may also contain consideration of how the work should be conducted and how the operators should be performing in their tasks. Additionally, it may include analysis of different types of physical and cognitive processes and requirements for interacting or interfacing with other systems or the operators. Sometimes requirements for other systems or the operators' situation awareness may be included in the analysis. This analysis of task performance and situation awareness is typically conducted using a cognitive task analysis.

Michigan Technical University System Development Lifecycle includes phases, during which documents, products and other defined work are created, reviewed, refined and approved. These phases are initiation, feasibility analysis, requirements analysis, design, development, implementation, operations and maintenance. The requirements analysis phase defines the detailed user requirements by using high-level requirements that are identified in the initiation and feasibility analysis phases. The requirements must be defined to an adequate level of detail to enable the system design to proceed on a proper manner. In the design phase, the system design is matured in more detailed level to fulfil functional requirements that are identified in the previous phases. The development phase consists of translating the detailed requirements into system components. Additionally, planning and testing of usability and information technology systems as well as requirements for integration may be included in the development phase. (Michigan Technical University, 2021).

2.1.1 Requirement management

International Organization for Standardization (ISO) standard 9000:2015 defines a requirement as “a need or expectation that is stated, generally implied or obligatory”. Requirements can be generated by customers or other stakeholders, or by the implementing organisation itself. (International Standardization Organization (ISO), 2015). The guide for requirement management defines a requirement as “an expression that describes a customer's will in relation to the characteristics of a business, performance, organization, product or service”. Requirement management ensures that requirements can be collected from all necessary parties and managed in a reliable manner in the organisation's processes. (Kosola 2013, p. 6-10).

Kosola explains that the basic function of requirements is to relay one party´s need to another as the basis for further planning and implementing that requirement. It is paramount that the requirements explicitly describe needs, not the implementation. Requirements are established in a design process, which describes how the previous level requirements are met in a most appropriate manner. In some situations, it is necessary to outline the connection between requirements and plans in order to understand the requirement. Plans that integrate requirements ino the whole, are concept of operation, use case description, implementation concept, system architecture or service description. Requirements are usually written in active tense and in imperative form. It must be known, what needs to be achieved and who needs to achieve it. Interactive workshops, seminars and brainstorming sessions are effective ways to gather stakeholder demands and expectations. The brainstorming workshop is a method, in which a small number of experts innovate various requirements. These requirements are then analysed, limited and formed into an actual requirements document. (Kosola 2013, p. 6-16 and 29-33).

2.1.2 Development of system-level technical requirements

According to MITRE Corporation (2021), system-level technical requirement is a general term to describe a system's functions, characteristics or constraints. It describes the users' needs and provides information for a system to comply with and meet legal restrictions or regulations and interoperate or integrate effectively with other systems or sub-systems. System-level technical requirements are developed usually after customer and user requirements have been defined. Initial system requirements may be drafted for developing a simulator or a prototype system to discover, clarify or confirm user requirements. A logical and efficient place to start developing system requirements is with the user requirements. In the context of this thesis, users’ needs are considered as results of the literature reviews and results of the cognitive task analysis.

2.2 Human factors engineering

Porathe, Prison and Man (2014) explain that human factors is a scientific discipline that tries to understand interactions among human beings and the other elements of a system, equipment and machines. Human factors applies theory, principles, data and methods to design and aims to optimise the human operators´ and system performance. According to Lee et al. (2017), human error is often a symptom of a poor design. Human factors aims to improve human interaction with systems by enhancing safety, reducing the risk of injury and death, increasing performance and productivity as well as quality and efficiency. The objectives are accomplished through the human factors design cycle that includes understanding, creating and evaluating the overall system. The cycle is iterative and begins with understanding the operators and the system they interact with. The next phase of the cycle is to establish solutions. The cycle finishes by testing, assessment or evaluation of how well the solutions achieve the operators´ objectives and goals. Human factors design includes an analysis of the operators´ tasks, objectives and goals and a design of human-machine-interfaces, interaction, task allocation, workload and organisation. (Porathe, Prison & Man, 2014, p. 4-5).

The challenges of human factors that concern remote-control centres for unmanned ships may include information overload, boredom, mistakes during changeovers and especially lack of the feel of the vessel. Additionally, constant reorientation to dynamic or new tasks, errors and delays in monitoring and control increase the remote operators´ workload. Some of identified challenges include limited situation awareness because of reduced sense of the ship movements and environment as well as information overload because of dense traffic conditions and multiple ship sensors. (Wahlström et al., 2015, p. 1039-1039).

2.2.1 Human system interaction

Ahvenjärvi (2016) states that remote operated or autonomous ships do not mean that there is no more a human element involved in the navigation process. Some types of the operators´ errors may be eliminated by autonomy, but the human element and human beings have to be considered. The role of the human element in remote-control system or the autonomous ship is similar to the role it has on the bridge of a manned ship. A user-centred design of the human machine interface of remote-control system is important to maximise the safety of the remotely controlled ship and minimise user errors.

According to human factors research, high levels of automation can put users out of the loop, decreasing levels of situation awareness (Endsley & Jones, 2011, p. 11). According to Lee et al. (2017), people are in-the-loop behaviour when they are actively attending and controlling the process. Monitoring the system is described as being on-the-loop behaviour, which requires constant attention and is hard to maintain. The limits of human attention make it difficult to be in-the loop with more than few activities. The effort may cause the operators to move out-of-the-loop and delegate responsibility to automation. The human operators are usually not good at monitoring or controlling a system with a high degree of autonomy that involve supervision of the operators who are away at a distance from the direct control.

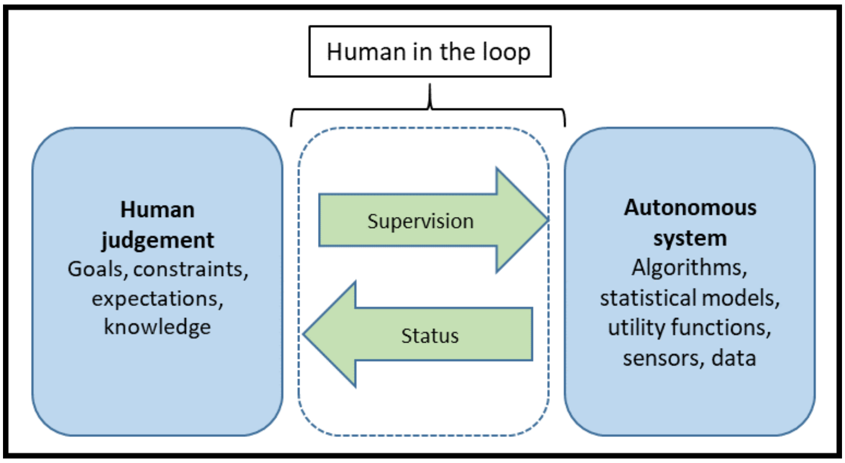

Figure 4: Human in the Loop. (Rahwan, 2017, p. 1).

Lee et al. (2017) also claim that there is a some kind of "sweet spot" in keeping the human operators in-the-loop in a way so situation awareness does not degrade and cause problems if automation fails. The system should have relatively high levels of automation at early phases of attention, perception and information integration assistance but probably not at high levels of automation in decision-making. According to Automation Direct (2021), there are many ways to develop human machine interface screens for machine automation and related applications. The look, feel and use of human-machine-interfaces (HMI) can be very different from each other with different kind of tools, object libraries, animation and colours that are usually available in modern software. Guidelines, standards and handbooks cover best practices of HMI design. They present and discuss design, development, operation and maintenance methods for effective HMI production and include safety, quality, reliability and efficient control of processes and equipment under normal and abnormal conditions. These guidelines can be used as a basis to create HMI design specifications for remote-control system, which in turn can be used to create consistent and effective HMIs.

2.2.2 Situation awareness

According to Endsley and Jones (2011), situation awareness (SA) is goal oriented and the elements of the environment that the operators need to be aware of are determined based on the goals that are defined in the operators´ tasks. Goal-Directed Task Analysis methodology is used to define what kind of data the operators need to be aware of, how that data needs to be understood relative to the operators´ goals and what projections need to be made to achieve these goals. Endsley (1995) defines SA formally as “the perception of 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”. The term situation awareness comes originally from military aviation. In common language, situation awareness is often explained as being aware of what is happening around you and understanding what that means now and in the near future. Awareness is usually defined as what is important information for a particular task or goal. (Endsley & Jones, 2011, p. 12-14). In the applied behavioural science, the term situation awareness has emerged as a psychological concept similar to such terms as intelligence, vigilance, attention, fatigue, stress, compatibility and workload (Pew & Mavor, 1998, p. 172).

Lee at al. (2017) explain that situation awareness describes the operators´ awareness and understanding of dynamic changes in their environment. Three levels of SA - perception (and selective attention), understanding and prediction - must be applied to a specific situation. An operator can´t have SA in practise, if what that awareness is or should be is not determined. SA itself does not define or incorporate actions that relates to decisions made from the operators´ awareness or assessment of the situation. (Lee et al., 2017, p. 228-229). Situation awareness is a key safety concern in use of unmanned maritime systems and prerequisite for sense and avoid capability. Adequate situation awareness for UMS is considered to include at least information, intelligence and control methods. Information in this case means the data required for execution of safe operations. Intelligence means the capability of the system to acquire, comprehend and apply information. Control methods include means to transfer data from control system to USV and back. (EDA, 2018, p. 33).

The formal definition of SA can be divided into three separate levels:

- SA level 1 means perception of the elements in the environment
- SA level 2 means comprehension of the current situation
- SA level 3 means projection of the future status (Endsley, 1995, p. 32-64; Endsley & Jones, 2011, p. 13-29).

The first level (perception) represents the initial information that the operators need in their work and it does not require mental processing. The second level (comprehension) means results of the operators´ evaluation of the current situation. The third level (projection) represents the information that requires mental processing and results in estimation about future events. The first step in achieving SA is to perceive the status, attributes and dynamics of relevant elements in the environment. A pilot needs to perceive important elements such as other aircraft, terrain, system status and warning lights. Perception of information may come through several senses, visual, auditory, tactile (haptic), taste or a combination of them. Most problems of the situation awareness in aviation tasks occur at SA level 1. 76% of errors in SA with pilots were related to not perceiving needed information correctly. (Endsley & Jones, 2011, p. 14). At SA level 1 for example, a navigator of a vessel needs to perceive other vessels, sea area and terrain, own ship´s and system´s status, warning lights along with their relevant characteristics by means of visual, auditory and other senses. One of the key questions is, how will the operation system support the operators in detecting and perceiving all relevant data correctly or adequately?

The second step in achieving good SA is understanding what perceived information means in relation to relevant operators´ goals and objectives. Comprehension is based on a synthesis of SA level 1 elements and a comparison of that information to the operators´ current goals. In practice it means integrating pieces of data to form information and prioritising combined information's importance and meaning to achieving present goals. Approximately 19% of SA errors in aviation tasks involve problems with SA level 2. (Endsley & Jones, 2011, p. 164). By understanding the importance of information, the operators with SA level 2 have associated a specific goal-related meaning and significance to current information. A crucial element of SA level 2 is understanding what perceived data means in relation to current goals and objectives that are set for the operation. Comprehension is based on synthesis of SA level 1 elements, integrating many pieces of data together to form complete information. (Endsley & Jones, 2011, p. 16-17).

Once the operators know what the elements are and what they mean in relation to the current goals, the ability to predict what those elements will do in the near future constitutes SA level 3. The use of current situation understanding to form projections requires a very good understanding of the domain and a highly developed mental models that can be mentally demanding. By constantly projecting ahead, the operators are able to develop a ready set of strategies and responses to events. This allows them to be proactive, avoiding many undesirable situations, and also respond quickly when events happen. The quality of prediction depends on how correctly the elements are perceived and comprehended related to the operators´ goals and objectives. (Endsley & Jones, 2011, p. 18).

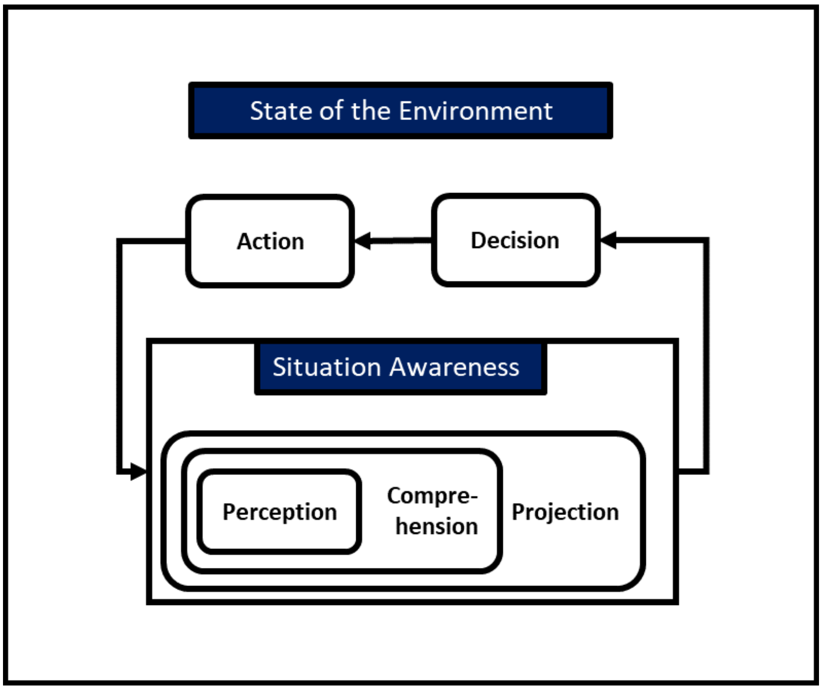

Figure 5: Three levels of situation awareness (Endsley 1995 p. 32–64; Endsley & Jones, 2011, p. 13-29).

Perception of time and the temporal dynamics of various elements play an important role in SA. The operators filter the situation based on time and space. Space means in this context how far away some element is and time how soon that element will have an impact on goals and tasks. Time is a strong part of SA level 2 (comprehension) and SA level 3 (projection of future events) (Endsley & Jones, 2011, p. 19). In remote navigation both space and time are crucial factors. It is important to detect objects of interest or hazards and understand how far they are and how fast they impact safe navigation or other operation. The remote operators may in some cases be required to make decisions in time constraint situations, possibly take the control over from the automatic or autonomous navigation system and steer the unmanned vessel in risky areas of narrow passages and very shallow water. This may be the situation especially in the archipelago where a number of rocks, islets, islands and other vessels can be very close to the remotely operated vessel.

According to Endsley and Jones (2011), the operators have different cognitive mechanisms upon which SA is built in their working memory. SA is the product of basic cognitive processes, mental functions that all operators have and they are quite consistent across different domains. The operators’ SA is influenced by what information they search and focus their attention to. The operators´ ability to perceive multiple items simultaneously is limited by their attention and this limits the amount of SA an individual operator can achieve. Elements that need frequent attention because of the importance or rate of change are usually monitored most often. Some information, such as audio and visual information, can be more easily processed simultaneously; however, it is difficult to process other types of information simultaneously. When information comes through the same senses, visual, auditory, tactile or smell, they consume same central processing resources and require the same response mechanism (e.g. speaking or writing). (Endsley & Jones, 2011, p. 20).

Endsley and Jones (2011) explain that the operators usually know what they are trying to accomplish within their tasks and goals. These goals help them to determine which environmental elements to pay attention to. The operators typically perform their tasks in goal-driven, top-down information processing and information is searched for in the environment that is relevant to the operators´ goals. In data-driven, bottom-up processing information captures the operators´ attention, completely independently of their goals. Incoming information is processed based on the priority of its natural perceptual characteristics. Flashing icons on a computer display may catch the operators´ attention, even if they are trying to read other information. Alarms, loud noises and red colour tend to catch attention as well. In goal-driven processing, SA is guided by the operators´ current goals and expectations, which affect how attention is directed and how information is perceived and interpreted. The operators´ goals and plans dictate what aspects of the surroundings are noticed. Perceived information is then blended and interpreted in light of these goals to form SA level 2. Active goals guide which mental models are chosen. Mental model plays an important role in directing attention to cues and information in the environment and interpreting those cues. Prioritising goals is critical to successfully achieving SA. If the operators focus on the wrong goals, they may not be receptive to the correct information or may not search needed information at all. Selected goals and mental models will be used to interpret and integrate perceived information in order to understand what the information means. Alternating between bottom-up data-driven and top-down goal-directed processing of information is one of the important mechanisms that support SA. If the process fails, SA can be severely damaged and being locked into only goal-driven processing can result in SA failures. (Endsley & Jones, 2011, p. 21-26).

According to Porathe, Prison and Man (2014), maintaining a high-level of situation awareness with unmanned ships is a challenge since the factors causing ship sense on-board needs to be located ashore. There is not any physical connection between the human operators and the vessel and the operators are not able to directly sense and perceive information from the ship's environment. Missing interaction emphasise many human factor issues regarding monitoring and controlling. It may be difficult for the remote-control center operators to perceive how the ship is behaving and what kind of environmental conditions the vessel is currently facing. The ship sense contains collecting and utilising information gathered from the outside environment and presented by the navigation and other systems. In close distances to other objects when navigating through an archipelago or when engaged in harbour manoeuvres and situations when there are many objects or hazards, the task is mainly visual and information about the ships motions is required. If there are no human operators on-board the vessel to sense heave, rolling and slamming, these motions have to be monitored by sensors. The data must be sent to the remote-control centre and displayed in some intuitive way to provide at least some kind of ship sense to the operators. Developing and maintaining high-level situation awareness on-board unmanned vessels requires a lot of attention for human factors. (Porathe, Prison & Man, 2014). Situation awareness requirements for unmanned vessel operations depend on the types of missions they to accomplish. Many unmanned vessels are involved in various types of search tasks, either in military applications or disaster response efforts. (Endsley & Jones, 2011, p. 223).

Situation awareness is a critical factor when any manned or unmanned ship navigate safely at sea or conduct operations on the surface, sub-merged or using assets in air-space depending on the mission and tasks of the ships or other assets. Situation awareness is being aware what is the status of own ship systems, cargo or payload, route, position, speed and tasks. Additionally, SA includes environmental conditions, positions and statuses of other ships, threats or hazardous obstacles, terrain and conditions and how does all that affect the operators´ plans and conduct of their tasks currently and in the near future.

2.2.3 Decision-making

Merriam-Webster dictionary (2020) defines a decision as "a choice that you make about something after thinking about it or the result of deciding". Lee et al. (2017) state that decision-making is a task in which a person must select one option from several alternatives. In decision-making the operators must interpret information for the alternatives, the timeframe is usually longer than a second and the choice includes uncertainty. Decision-making includes usually risks, because there may be consequences if the wrong alternative is chosen. Decision-making includes typically four phases, gathering and integrating information relevant for the decision, interpreting and assessing the meaning of this information, planning and choosing the best course of action after considering the costs and values of different outcomes, and monitoring and correcting the chosen course of action. Principles of improving decision-making in system design include task re-design, limiting the number of options, selecting useful defaults, making choices concrete, creating linear and comparable relationships as well as sequencing and separating choices. It may also contain using of procedure and checklists, integrated, graphical displays, automation and decision-making support tools. Tools can include diagnosis and situation assessment, treatments, choice and course of action recommendation support. (Lee et al., 2017, p. 209 and 228).

According to University of Massachusetts (2021), decision-making is the process of making choices, gathering information and assessing alternative resolutions, identifying the alternatives, weighing the evidence, choosing among alternatives and taking actions. The process includes usually reviewing decisions and consequences. A step-by-step decision-making process helps to make more deliberate, thoughtful decisions by organizing relevant information and defining alternatives increasing possibility to choose the most satisfying alternative possible.

The OODA loop stands for Observe-Orient-Decide-Act. The loop begins with making observations about what is happening in the environment, outside information, unfolding circumstances and implicit guidance and control. The orientation involves understanding, cross-referencing and combining genetic heritage, cultural traditions, analysis and synthesis, previous experiences and new information. Deciding may involve making the decision hypothesis. The last component of the loop includes implementing an action. The action unfolds and interacts with the environment and the process starts all over again. One model for forming situational awareness is Perceive-Understand-Predict (PUP). Responders should use situational awareness as the foundation for good decision making. PUP is not a decision-making model; however, it supplements the decision-making model. (Gasaway, 2018, p. 1).

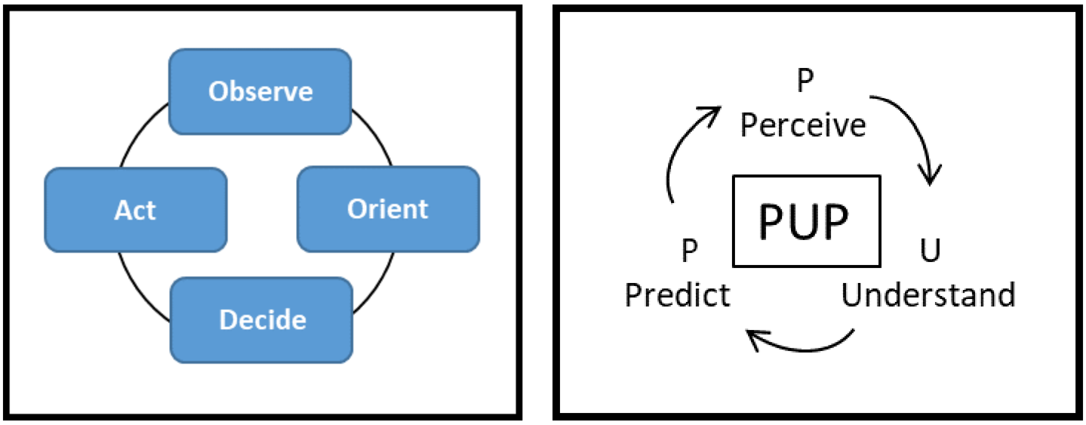

Figure 6: OODA-loop and Figure 7: PUP-loop. (Gasaway, 2018, p.1).

Dynamic decision-making Process (DDM) is similar to the OODA loop except, it adds anticipating of outcomes to the process before executing the action. The process contains focusing attention to maximum of 5-7 critical clues and cues, comparison of the current situation to past experiences, evaluation of new information, decision-making, anticipation of the outcome of the decision and implementing the action. If the anticipated outcome of the decision is not adequate, previous steps shall be repeated until feasible plan is established. The main difference between the OODA loop and the DDM model is anticipating the outcome of the decision before implementing the action plan. (Gasaway, 2018, p. 2).

2.2.4 Command and control

The Development, Concepts and Doctrine Centre defines command as the authority assigned to a person of the armed forces for the direction, coordination, and control of military forces. Control is defined as the authority exercised by a commander over part of the activities of subordinate organisations that contains the responsibility for implementing orders or directives. Command and control (C2) can be a process, a capability, a system or a structure. It can also be treated as a single whole, “command and control”, with a different meaning to the separate words command and control. (Ministry of Defence of the United Kingdom, 2017, p. 8).

Merriam-Webster dictionary (2020) defines the meaning of command as “to direct authoritatively, to exercise a dominating influence over, to demand or receive as one's due or to have military command of as senior officer”. Control means “to exercise restraining or directing influence over, to have power over or power or authority to guide or manage”.

(Merriam-Webster dictionary, 2020). Babicz (2015) defines control as “a process of expressing a command or an order to enable the desired action to be done”. Automatic control denotes predetermined orders without the operators´ action. Local control is a system located on or close to a machine that enables its operation within sight of the operator. Remote-control is a device or devices that are connected to a machine by mechanical, electrical, pneumatic, hydraulic or other means and by which the machine may be operated remotely from, and not necessarily within sight of the operator.

Command and control capability is a dynamic and adaptive socio-technical system configured to design and execute joint action. Command and Control is a complex system, which must be capable of adapting to meet the requirements of changing environment, context and mission being agile. Essential functions needed for C2 to achieve its purpose include at least creating shared awareness, allocating resources to create effects, assessing progress and recognising the need to change the action plan. (Ministry of Defence of the United Kingdom, 2017, p. 11).

2.2.5 Task analysis

Task analysis is a way of systematically describing human interaction with a system to understand how to match the demands of the system to human capabilities. Task analysis contains usually techniques, use cases, user stories and user journeys. Techniques focus on understanding the users' goals and motivations, the tasks and subtasks to achieve these goals, the ordering and timing of these tasks as well as the location and situation where tasks occur. Task analysis is an iterative process that starts with defining the purpose and identifying the required data by defining the design considerations to be addressed. Next steps include collecting and interpreting task data and ends with innovating from task data. A hierarchical task structure is established during interviews and revised or updated during the process. (Lee et al., 2017, p. 27).

Lee et al. (2017) defines four categories of information that are usually collected regardless if the task analysis is focused on the physical or cognitive aspects of the activity.

- Hierarchical relationships: What, why and how tasks are performed?
- Information flow: Who performs the tasks, with what indications and with what feedback?
- Sequence and timing; When, in what order and how long tasks take to perform?

- Location and environmental context: Where and under what physical and social conditions tasks are performed? (Lee et al., 2017, p. 28).

Hierarchical Task Analysis (HTA) is used to describe systems in terms of their goals, sub-goals and operations. HTA works by decomposing activities into a hierarchy of goals, subordinate goals, operations and plans. HTA is concerned with goals and objectives or end states that are hierarchically decomposed. HTA focuses on what the operator is required to do regarding actions and cognitive processes to achieve the system goals. HTA outputs define the overall goal of a system, the sub-goals to be undertaken to achieve the overall goal, the operations required to achieve each of the sub-goals. Plans specify the sequence and under what conditions sub-goals have to be achieved in order to satisfy the requirements of the subordinate goal. HTA process includes collecting data about the task or system by observation, questionnaires, interviews with SME´s, walkthroughs, user trials and documentation review. HTA has been applied to interface design and evaluation, allocation of functions, team task analysis, workload assessment and procedure design. HTA is particularly useful in system development. (Stanton et al., 2009, p. 12 and 39). Hierarchical Task Analysis used in this thesis is a Goal-Directed Task Analysis. The task analysis contains the remote operators´ navigation tasks and focuses on the goals the operators must accomplish in order to successfully perform the tasks, decisions that the operators must make to achieve the goals and the information requirements that are needed in order to make appropriate decisions. The GDTA is further explained in Chapter 3.

2.3 Autonomous and unmanned ships

IMO defines MASS as a ship which can operate independent of human interaction (IMO, 2021, p. 3-4). An autonomous ship is not necessarily unmanned but can be controlled by automatic systems for navigation and engine control. Systems are pre-programed in a similar way than a track pilot follows a pre-recorded voyage plan. The autonomous system may include a certain level of artificial intelligence and may be able to detect and identify other vessels and do collision avoidance manoeuvres according to the International Regulations for Preventing Collisions at Sea (COLREGS). (Porathe, Prison & Man, 2014).

According to Bureau Veritas (2019), an autonomous ship shall be capable of managing a predefined voyage plan and updating it in real-time. It shall be capable of navigating according to the pre-defined voyage plan and avoid collisions with obstacles and other vessels or objects. The autonomous vessel shall also be able to keep a sufficient level of manoeuvrability and stability in different sea states, withstand unauthorized physical or virtual trespassing and comply with all relevant international and local regulations. The possibility for the crew or the remote operators to regain control of a ship in case of emergency or system failure should always be possible.

Term unmanned ship means a vessel that has no crew on-board and autonomous ship means that the vessel can operate without human intervention. Autonomous may refer to one or more ship functions, during ship operations or voyage. Autonomous ship system includes all physical and human elements that together ensure sustainable operation of an autonomous vessel. The operation type should define the purpose of the MASS and its main operational phases. For example, a cargo ship voyage might comprise loading, departure, voyage, arrival and unloading. A MASS may transit at high speed to a survey area, during which one method of control may be appropriate, but when on station may operate at a much lower speed, which may materially change the risk of operation and allow a different level of control during this phase. (Maritime UK, 2021, p. 18-21 and 25).

According to EDA (2018), unmanned maritime vehicles (UMV) are defined as remotely controlled or autonomous craft, vessels or ships with the ability to function without a bridge crew on-board. UMV can be categorised by functions related to navigation and manoeuvring (functions without any human on-board control) or functions related to purpose, operation, tasks, mission other functions (functions may be manned). An unmanned surface vehicle (USV) is a vehicle which operates autonomously or is controlled and commanded remotely. EDA (2018) defines 44 operational safety regulation guidelines and 86 design guidelines that should be considered to achieve a safe unmanned operation. These design guidelines consist of natural and operational environment considerations, general performance, failures, mishaps and hazardous situation management, platform considerations, support system considerations, control system, platform control system, communications link and mission equipment-oriented considerations. (EDA, 2018, p. 17-32).

The MUNIN (2015) project propose a concept, where the ship is autonomously operated by new systems on-board the vessel; however, the monitoring and controlling functionalities are executed by an operator ashore. The concept defines an advanced sensor module, an autonomous navigation system, an autonomous engine and monitoring control system and implements them as prototypes. An advanced sensor module takes care of the lookout duties on-board the vessel by continuously fusing sensor data from existing navigational systems combined with modern daylight and night-vision cameras. An autonomous navigation system follows a predefined voyage plan with a certain degree of freedom to adjust the route autonomously due to an arising collision situation or significant weather changes. An autonomous engine monitoring and control system supports ship engine automation systems with failure-pre-detection functionalities and aims to keep optimal efficiency. (EC, 2015, p. 1-12).

If we can assume that the human element is present on similar level on the bridge on-board a vessel and in the remote-control system and if the remote operators have sufficient situation awareness, we can hypothetically assume that the operations and tasks conducted are basically similar in the remote-control system than on the bridge. If the quality and level of information in the remote-control system is the same or better than on the bridge and level of SA is equal or better provided by remote-control system than on the bridge, the operations conducted and tasks to be completed should be rather similar on both locations.

The DNV GL group technology and research position document states that a ship is operated by means of separate functions that fulfil the objectives of the ship's operation. For most ship types, navigation is the main function of the ship. (DNV, 2018b, p. 6). DNV has divided the ship functions into four sub-tasks that are condition detection, condition analysis, action planning, and action control, in order to analyse the human involvement in a function as depicted in the figure below.

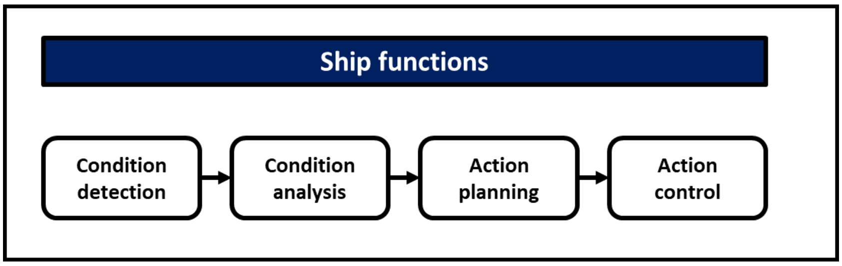

Figure 8: Generic breakdown of a ship navigation function into sub-tasks. (DNV, 2018b, p. 6).

Ship functions such as watertight integrity, stability, mooring and anchoring are common to most ships and other ship functions. Functions are completely dependent on the mission profile of the ship. It must be clearly determined how functions to detect, analyse, plan and control are executed without crew on-board autonomous or unmanned ships. If a ship is completely unmanned, all required ship functions must be carried out remotely or autonomously. (DNV, 2018b, p.13).

2.4 Levels of autonomy and control

Lloyd's Register, Det Norske Veritas GL and International Maritime Organisation define levels and degrees autonomy in the maritime domain. LR Design and Construction Design Code defines six levels, DNV class guideline five levels and IMO MASS scoping exercise defines four degrees of autonomy. MASS can operate at one or more levels or degrees of autonomy during a single voyage. Definitions are combined and presented together with associated functions and the operator’s roles.

Level or degree of autonomy	Associated functions	Operators´ role
LR level 0 Manual	No autonomous functions. All actions and decision-making are performed manually. Systems may have level of autonomy.	Human operators are in or on the loop and control all actions manually.
DNV level M Manual	Manually operated function.	Human operator controls the system manually.
LR level 1 On-board Decision support	All actions are taken by human operators. Decision support tool can present options or otherwise influence actions. Data is provided by systems on-board.	Operators set course as waypoints and speed. Operators monitor and change course and speed when necessary.
DNV level DS Decisions are supported	System decision supported function.	Operators make decisions supported by the system.
IMO Degree 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 sometimes be unsupervised.	Seafarers on-board are ready to take control. Navigation is based on enhanced decision support systems supporting on-board operators performing navigational tasks.

Level or degree of autonomy	Associated functions	Operators´ role
LR level 2 On-board and off-board decision support	All actions are taken by human operator, but decision support tool can present options or otherwise influence the actions chosen. Data may be provided by systems on or off-board.	Operators monitor operations and surroundings and change course and speed if needed. Suggestions for interventions may be provided by algorithms.
DNV level DSE Decision Support Execution	System supports decisions with conditional system execution capabilities.	Operators are in the loop and acknowledge actions before execution.
IMO Degree two	Remotely controlled ship with seafarers available on-board.	The ship is controlled and operated from another location. Seafarers are on board to take control and to operate the shipboard systems and functions.
LR level 3 Active human operators are in the loop	Decisions and actions are performed with human supervision. Data may be provided by systems on or off-board.	Operators monitor system's functions and actions and authorise actions before they are carried out.
LR level 4 Human operators are on the loop and supervise.	Decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to let operators the to intercede and over-ride.	Operators monitor system's actions, and takes correctional actions when needed.
DNV level SC Self-controlled, human operators are on the loop.	Self-controlled function. The system will execute the operation.	The system will execute the operation, but the human operators are able to override the action.
IMO Degree three	Remotely controlled ship without seafarers on-board. The ship is controlled and operated from another location. There are no seafarers on board.	Remote operators perform tasks as they were on the bridge. Watch officer is being covered by personnel in an off-ship remote control centre.

Level or degree of autonomy	Associated functions	Operators´ role
LR level 5 Fully autonomous	Rarely supervised operation where decisions are entirely made and actioned by the system. The system performs calculated actions.	General goals are determined by operators. Operators are alerted unless the system is very certain of its interpretation of the surroundings, its own state and following calculated actions.
LR level 6 Fully autonomous	Unsupervised operation where decisions are entirely made and actioned by the system during the mission. General goals may be determined by the system. The system makes its own decisions and actions, calculating own capability and prediction of the behaviour of surrounding traffic.	Operators are alerted in case the system fails to determine action.
DNV level A Autonomous	Autonomous function. The system will execute the function, normally without the possibility for a human to intervene on the functional level.	Operators possibly monitor or supervise when required.
IMO Degree four	Fully autonomous ship. The operating system of the ship is able to make decisions and determine actions by itself.	Remote operators perform tasks as they were on the bridge or are possibly only monitoring or supervisioning when required.

Table 1: Levels and degrees of autonomy, associated functions and the operators´ roles (LR, 2017, p. 4-5; DNV, 2018a, p. 8 and 5; IMO, 2021, p. 3-4). Higher autonomy level (AL) system may use a lower AL system as part of its reversionary control and a complex system may be a combination of multiple systems at different levels.

Levels of control (LoC) are defined in Maritime UK Industry Principles and Code for MASS (2021). EDA (2018) delineates the control levels. Levels of control range from manned on-board control (method zero) to autonomous control (method five). The level of control may change over time, operational situation, tasks and phases during a mission. (EDA, 2018, p. 5-8). Levels of control and control task allocation between the human operators and the system are summarised in table 2.

Level	Name	MASS/USV or the system	Operators´ role
0	Crewed	MASS/USV is controlled by operators on-board.	All controls are conducted by human operators on-board.
1	Operated or remote control	MASS/USV or the system may provide sensor data but has no reasoning capability.	Operators conduct all cognitive functions, analysing, planning, decision-making. They have direct contact with MASS/USV over continuous data transfer. Operators control the system and all mission functions and may receive feedback of performance and observations of systems behaviour.
2	Directed or permissive	Some degree of reasoning and ability to respond is given to MASS/USV. It may sense the environment, report its state and suggest one or several actions. MASS/USV may suggest possible actions, prompt operators for information, decisions or ask permission. It will act only if commanded and/or permitted.	Operators have authority to make decisions.
3	Delegated or declaration	MASS/USV is authorised to execute some functions. It may sense environment, define actions, report intentions and state. The system alerts the progress and exceptions. The initiative emanates from MASS and functions are executed automatically if the operator fails to react within a time limit.	Decision-making is shared between operators and systems. Operators may override or alter parameters, cancel or redirect actions. Operators may object to intentions declared by MASS during a certain time, after which MASS will act.
4	Monitored or reporting	MASS/USV senses the environment and report its state. Systems defines actions, decides, acts and reports actions and state to operators. The system executes functions without waiting or expecting a reaction.	Operators monitor the events.
5	Autonomous	MASS/USV senses the environment, defines possible actions, decides and acts. Crewless Vessel is afforded a maximum degree of independence and self-determination. Autonomous functions are invoked by on board systems without notifying operators.	

Table 2: Levels of control and control task allocation between the human operators and the system. LoC should be considered alongside the levels (degrees) of autonomy in table 2. Levels of control may be different for different functions on-board the same USV/MASS. A vessel navigating under LoC 4, may also deploy a payload that is controlled at LoC 2. The LoC applied to the vessel may also change during a voyage, LoC 1 in a VTS, but LoC 4 in open ocean passage. The planned control methods and associated LoC should be clearly defined and may vary across different phases of a voyage. (Maritime UK, 2021, p. 20, 21 and 26; EDA, 2018, p. 5-8).

The autonomous control is divided into deliberate and emergent based on quality of communication and into deterministic or non-deterministic control based on the degree of change in on-board plans. Deliberate autonomy means that lack of communication is intentional and planned. In that case the USV shall be equipped with the appropriate means for autonomous functions and its behaviour is predictable. Emergent autonomy means that lack of communication is not intended or planned. The USV may not be equipped for autonomous control or it may otherwise be not intended and the resulting functionality may be inappropriate and unpredictable. Deterministic control utilises mission plan that is prepared by the operators before the mission starts and is not altered during the mission. The detailed behaviour of the system can be predicted by simultaneous simulation of the mission. Non deterministic control utilises mission plan that is initially planned by the operators before the mission starts and may be changed during the mission without the operator´s interaction by on-board mission planning capability. (EDA, 2018, p. 5-8). Levels of autonomy, associated functions and the operators´ roles as well as levels of control are issued as guidelines; however, they shall be considered in the GDTA of remote navigation tasks and when further analysing the design requirements for an unmanned surface vessel remote-control system.

3 Research Methodology

Mainly qualitative methodology is used in this thesis. The research problem and questions are examined mainly by compiling and analysing sources using literature research methods from the user's point of view. Results of literature reviews and analysis are complemented by cognitive Goal-Directed Task Analysis to determine requirements for the remote-control system design. Selected standards, guidelines and best practises are analysed in literature review. Human factors literature and research are studied and reviewed to complement the literature review. Cognitive task analysis is used to determine what information, decisions and situation awareness are required in conducting successful remote navigation tasks.

Main sources of the thesis are the standards and guidelines developed by international organisations and classification companies, the best practices of various research projects and principles and methods presented in the human factors literature that guide and define system design from a user-centred perspective. The perspective of the thesis is human activity as an operator and its support through system design, with some automation and autonomous features. Literature review of standards, guidelines and best practices seek to determine general system requirements for to remote-control. One aim is to use the literature and research results in the field of human factors to verify the requirements of the standards, guidelines and best practice guidelines and to supplement them from the operators´ point of view.

IMO´s and classification companies BV´s, DNV´s and LR's documents for autonomous and remote-controlled ships are selected as sources for this study regarding standards and guidelines. The study utilises also best practices documented in the final reports of research projects EDA SARUMS, MUNIN and Maritime UK Industry Conduct Principles and Code of Practice. The requirements, guidelines or best practises are analysed and compiled to form requirements for system design when seen feasible to the context of the thesis. The results of literature review regarding standards and guidelines give framework to human centred design requirements for the remote-control system. Literature review of human factors publications and research provide the human operator´s perspective to the requirements for system design. The results of the review are compiled in the analysis and system requirements.

An essential part of the thesis is a Goal-Directed Task Analysis using cognitive task analysis methods. The GDTA aims to determine the goals and tasks for the remote-control system operators, what information the operators need for decision-making and situation awareness requirements. The analysis and results of GDTA are presented in Chapter 7 and Appendices 1 and 2. The GDTA analyses dynamic information requirements relevant in a certain domain rather than static system knowledge. The information that changes dynamically throughout the course of task performance rather than focusing on general system knowledge the operators must possess in order to perform the in emphasized. These dynamic information needs are the operators' SA requirements. (Endsley & Jones, 2011, p. 63).

According to Endsley and Jones (2011), developing a GDTA requires interviewing experienced operators to identify the goals, decisions and SA requirements. During the GDTA, a series of semi-structured interviews are conducted. Interviews with subject matter experts (SME) are an indispensable source for information gathering for the GDTA. The interviews focus on goals and information requirements rather than technology or system specific displays or task flows. The results of interviews are combined with knowledge gained from other sources (analysis of written materials and documentation or verbal protocol) to create the initial GDTA. The initial GDTA is then validated by a number of experienced operators or SMEs to ensure that it includes all relevant goals, decisions and other information or requirements. The GDTA is formatted in a hierarchical manner to provide an easy trace from the goals to requirements. (Endsley & Jones, 2011, p. 64).

Rummukainen et al. (2015) state that the interviewees for the GDTA shall be subject matter experts who have extensive knowledge of an operator's job. The research results from the GDTA are typically divided into two categories including the operator goal hierarchy and the situation awareness requirements. After constructing the goal hierarchy and analysing the interview data further, incident-related information and system-related information blocks can be found. Incident-related information includes all the possible information that can be gathered during an incident. System related information means system characteristics that include system status, its purpose, and service dependencies. (Rummukainen et al. 2015).

In this thesis the GDTA goal hierarchy is constructed as a results of literature review, interviews, brainstorming and workshops together with SMEs. The goal hierarchy consist of one major goal and four sub-level one goals and several sublevel two to four goals. The operators must achieve these goals to have good situation awareness of the state of the system. In order to achieve that, they need information about the current systems and they need to identify, be aware of and understand current incidents in the monitored environment. The practical conduct of the GDTA is explained in Chapter 7. The analysis concentrates on remote navigation tasks, situation awareness related to navigation and management of control of the USV. The operation management system is considered from the perspective of operation planning, situation awareness, decision-making, execution (command and control) and feedback. Requirements for remote-control system are established using literature review, interviews, workshops and analysis methods such as task, operational and technical analysis.

4 Requirements, guidelines and functions for remote-control centre

Chapter 4 answers the first research question, “What is a remote-control centre?” and contributes to the fourth research question, “What are system requirements for a remote-control system from user-centred perspective?” by reviewing standards, guidelines and best practises related to remote-control centre, navigation tasks as well as monitoring and controlling.

The autonomy degrees two and three presented in Chapter 2 state that remotely controlled vessel may be with or without seafarers on-board and the ship may be controlled and operated from another location. Operating the vessel on autonomy level two, some seafarers can be available on-board to take control and to operate the shipboard systems and functions and remote navigational watch is based on the tasks, duties and responsibilities of an officer in charge of the navigational watch supported by personnel in an off-ship remote-control system. Operating the vessel on autonomy level three, there are no seafarers on-board and the vessel is controlled and operated from another location. The remote operators perform tasks as they were on the bridge.

According to Aboa Mare (2018), remote operations means operating of any technical system or machine from outside of it. Autonomous an unmanned vessels need to be paired with remote operations centres regardless of the degree of autonomy. In this thesis terms remote-control centre and shore control centre are considered to mean the same. Remote-control station is defined as a sub-system of a remote-control centre or a sub-module of an operation management system.

4.1 Remote-control centre

According to Maritime UK (2021), a remote-control centre (RCC) is a site off the ship from which monitoring and control of an autonomous ship can be executed. The remote-control centre may be located either ashore or afloat and may execute different degrees of control as defined in levels of control. RCC may consist of more than one control stations or rooms.

Remote-control station is “a location equipped with means and systems of remote-control and monitoring”. Control system is “an arrangement of elements interconnected and interacting in order to maintain, or to affect in a prescribed manner, some condition of a body, process or machine, which forms part of the system” (Babicz, 2015, p. 143).

Remote-control centre continuously monitors and controls autonomous and remotely operated vessels after they have been released from crew. RCC usually includes a situation room team that takes over direct remote-control of a vessel in certain situations. There may be a shore side replica of the unmanned vessels bridge including a remote manoeuvring support system that ensures an appropriate situation awareness and direct control despite the physical distance of crew and vessel. The remote-control centre operators may presumably monitor several autonomous ships at the same time and control the vessels by for example giving high level commands like updating the voyage plan. Tasks of the control centre focus on monitoring the operational status of the vessel and it provides the capability to take over direct remote-control in extraordinary situations. One of the main challenges seems to be keeping the remote operators´ situation awareness on adequate level when they work outside the vessel on a shore based facility or on-board another ship. The Human-Machine-Interface must be developed using decision-making heuristics that support the operators´ ability to establish and maintain situational awareness and remain in the loop in decision-making and to achieve objectives of safe unmanned and autonomous shipping. (EC, 2015, p 3-14).

Wahlström et al. (2015) claim that the basic functions of RCC contain monitoring the voyage and updating ship´s route according to weather situation, nautical traffic and navigational warnings. Functions include monitoring the ship´s health, satellite communication signal status and communication with other ships including decision-making in view of all of the above. The RCC operators have to make various non-self-evident decisions in considering issues such as weather, ship condition and maintenance needs, vessel traffic, and cargo. RCCs should execute agile command and control since vessels are operated from a distant location from which there is no direct human sensory contact to vessels.

It is important to define what relevant information for the remote operators is in order to conduct successful remote operations. The RCC operators´ performance will most likely decline when they are imposed to too much information (Kari et al., 2018, p. 584). When a human operator is in charge of decision-making, the location of the decision-maker should be clearly described, especially whenever human intervention is expected on-board, or from a RCC or combination of persons on-board and the operators in RCC. Special attention should be placed on the timing aspects and the ability of the human operators to establish sufficient situational awareness in order to take correct actions within reasonable time (command latency). (DNV, 2018a, p. 28). The remote operators should have adequate enough situation awareness to ensure that the remote operation is performed in a safe way and equal to the level of when the function is being performed by crew on-board. The required level of situation awareness for a remote operator should be considered together with automatic support and automatic control functions implemented to handle normal and abnormal conditions. (DNV, 2018a, p. 79).

The human element is present in remotely controlled operations in the same way as it is on the bridge of the manned ship. Maintaining situation awareness is essential for safe and efficient control of the ship and high quality of information presented to the human operators in RCC is crucial. The RCC operators require up-to-date essential information about the status of the ship, environment and traffic situation around the vessel. If the operators in RCC get exactly the same information that would be available on the bridge of the ship, there should not be any difference between the remote-control and the on-board control. (Ahvenjärvi, 2016, p. 520.). Manning of RCC may vary depending on the ship and type of operations. When the operators in a remote location are responsible for the operation of a function on-board a vessel, the remote operators need sufficient situation awareness to provide a firm basis for analysing the situation, planning actions and executing remote-control. The situation awareness necessary for the remote operators depend on the level of automation and decision support functionalities. (DNV, 2018a, p. 85).

The USV operations requires adequate responsibilities that are clearly allocated to the operators. The conduct of operation and USV mission may include roles and responsibilities of commanding officer (CO), watch officer(s) and controller(s). Persons conducting these tasks and roles are the operators of the system. The CO of an USV is considered to be the master of vessel therefore the overall responsibility during the UMS operation lies with the CO. The CO has the overall responsibility for the USV and for all UMS operations. The controller is responsible of mission planning, execution and post mission evaluation and executing orders from the CO. Controller is responsible of operations when the USV is under his or her control, adequate cooperation and communication with the payload operator and other personnel handling the USV. The controller has the responsibility throughout the USV’s operation regardless if the control is delegated to the system. (EDA, 2018, p. 8-10).

Distributions of roles and responsibilities should be clearly defined on-board a vessel between automation systems and the crew and in the RCC between automation systems and the remote operators and between the crew and the remote operators. (Bureau Veritas (BV), 2019, p. 12).

The control system consists of equipment needed for assuming command of one or more vessels or vehicles. Support system may consist of maintenance equipment, training facilities, documentation and other logistics. Roles and responsibilities of the operators controlling an USV include one person to assume the role of master or commanding officer for the UMV and at least one person at the control system that assumes the role of controller for the operational UMS. The exception is for an autonomous UMV, which may not have a controller or control system. (EDA, 2018, p. 3-4). Remote-control systems are typically sub-divided to mission planning, mission control, communication, mission evaluation and interface systems. Systems typically contain computers hardware, operating system and software. Controllers console may be integrated or portable. Communication system may contain UHF and VHF radio communication system, IRIDIUM satellite communication system, hydro acoustic communication system and local communication system (W-LAN). Mission evaluation system may consists of mission evaluation and simulation computers. Interface system include interfaces to command and control and other required systems. (EDA, 2018, p. A2-3-A2-4).

4.2 Standards and guidelines regarding remote-control centre

International Organization for Standardization publishes a set of standards that regulate design of control centres. ISO is assessing existing instruments to see how they might apply to ships with varying degrees of automation, through a regulatory scoping exercise on Maritime Autonomous Surface Ships (MASS). ISO 11064 consists Ergonomic design of control centres parts 1–8 (ISO, 2000-2013). A general prerequisite is that the remote-control centre and system design shall comply with this series of standards.
Part 1: Principles for the design of control centres.
Part 2: Principles for the arrangement of control suites.
Part 3: Control room layout.
Part 4: Layout and dimensions of workstations.
Part 5: Displays and controls.
Part 6: Environmental requirements for control centres.
Part 7: Principles for the evaluation of control centres.

Part 8: Ergonomic requirements for specific applications.

Classification publications from Bureau Veritas, Det Norske Veritas and Lloyd´s Register include design and construction codes and class guidelines for unmanned marine systems and guide for autonomous and remotely operated ships. These publications give guidance for designing and operating the unmanned vessels. BV guidelines for autonomous shipping gives guidance and recommendations for designing and operating systems to enhance automation in shipping. BV rules for the classification of high speed craft gives classification guidance on structures, arrangements, safety and handling, controllability, performance and operational requirements. (BV, 2022 and 2019). DNV class guidelines for autonomous and remotely operated ships contain methods, technical requirements, principles and acceptance criteria related to class objects as referred to from the rules. The guidelines provide a framework and main principles for assessment of autonomous and remotely operated vessels, guidance to arrangements and technologies supporting remote-control of navigation functions, guidance for remote-control of engineering functions and technical guidance to arrangements in the remote-control centre. (DNV, 2018a and 2018b).

DNV technical arrangements guidance regarding RCCs aims to ensure that remote-control and supervision, in combination with automation systems, will provide a level of safety equal or better than, if the functions are controlled and supervised from on-board a vessel. The guidelines includes as follows:

- Arrangements in the RCC, remote workstations and workstation layout.
- Hazards and barriers, redundancy, fault tolerance, equipment and power supply.
- Remote situational awareness, real-time situational awareness and senses
- Remote vessel supervision, independent supervision, intended action control, pre-warning, alert management, functional status, consequence analysis and decision support, contingency plans and data logging. (DNV, 2018a, p. 83-90).

LR Design and Construction Code for Unmanned Marine Systems provides a framework for the assurance of safety and operational requirements for unmanned maritime system. The construction code sets scope, goals, functional objectives and performance requirements for UMS structure, stability, control, electrical, navigation, propulsion, manoeuvring, fire control and auxiliary systems. LR code is applicable to autonomous vehicles and remote-controlled vehicles operated above or below the surface. (LR, 2017, p. 1-5).

Maritime Autonomous Systems Regulatory Working Group Industry Conduct Principles and Code of Practice for Maritime Autonomous Ship Systems (Maritime UK 2021) gives guidance, standards and best practices for designing, building, operating and controlling autonomous and semi-autonomous MASS, primarily less than 24 metres. MASS in this context means both autonomous and remotely controlled ship systems. The publication focusses on surface ships, seagoing vessels and watercraft in accordance with SOLAS Chapter V, Safety of Navigation. The code of practise gives guidelines for RCC human resources and technical requirements. The guidelines aligns with the LR Crewless Marine Systems Code and the EDA-sponsored Best Practice Guide for Crewless Maritime Systems (Maritime UK, 2021, p. 4-5).

The guide of Engineering Equipment and Materials Users Association (EEMUA) provides guidance for designing of control rooms, consoles and human machine interfaces and a checklist for and evaluating the design of them. (Stanton et al., 2009, p. 123). The activities and functions of remote-control system seems to fit into this category because the role is to supervise, monitor and control assigned vessels. EEMUA guide checklist provides a practical tool for evaluating and designing supervisory control and data acquisition systems. The guide and the checklist are analytical tools to assess whether the system under design or evaluation fulfils the compliancy of the EEMUA requirements. Checklist may be used for example in the design process when planning the layout, arrangements, functionalities and HMIs in the remote-control system or evaluating systems that are to be integrated to the remote-operation system. (Engineering Equipment and Materials Users Association, 2019).

4.3 Functions of remote-control centre

RCC has two major activities or missions to accomplish. These activities or missions can be allocated to several sub-activities, -functions or -tasks. The major activities are monitoring, including condition detection and analysis and controlling, including action planning and control. One example of a controlling of a navigation function in the remote-control centre is presented in Figure 8. The main principle in the example is that the combined human and machine capabilities, for example in condition detection, should be on the same or better level in the remote-control centre than on-board a ship in order to achieve an equal or better level of safety.

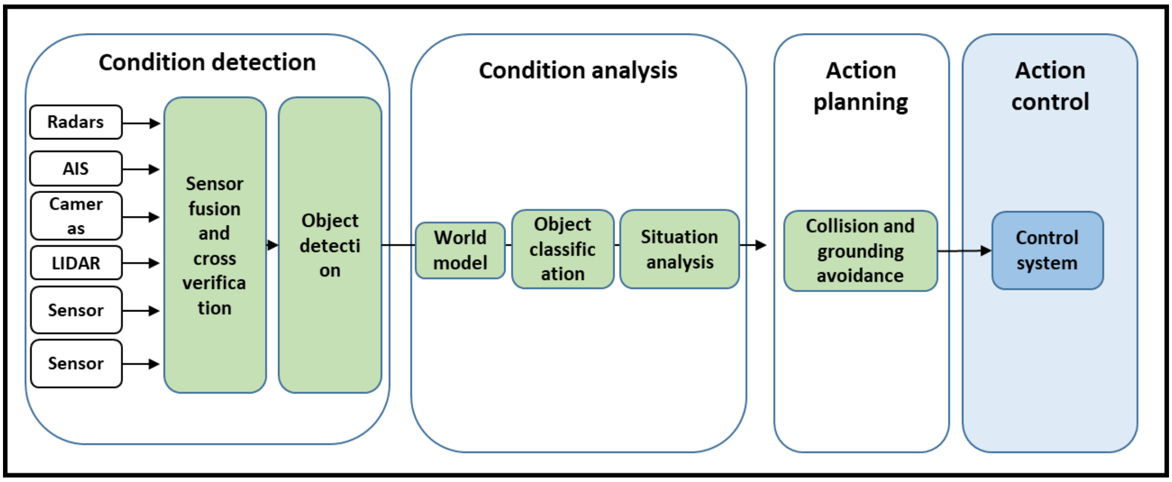

Figure 9: Control of a function. Dividing the control of a function into the above sub-tasks is in general suitable for any function, but is in particular relevant for the navigation function (DNV, 2018a, p. 52).

Operation of the function in the remote location should be based on real-time situational awareness for the remote operator. Real-time information should not be based only on observations by personnel on-board. (DNV, 2018a, p. 85). The ship navigation functions with four sub-tasks are condition detection, condition analysis, action planning and action control. These functions require currently some level of human involvement in remote operations. The functions are further analysed in the Goal-Directed Task Analysis. The DNV group technology and research position document (DNV 2018b) includes condition monitoring, decision support, operations optimization, remote-control and on-board automation. DNV introduces novel technologies that shall be considered when designing technical features and human factors such as the operator´s performance in remote-control centre as depicted in the following figure.

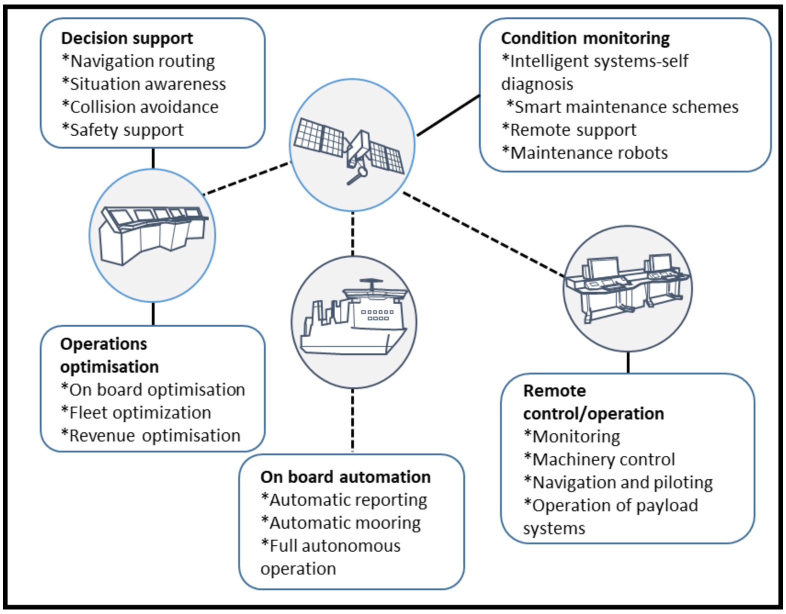

Figure 10: Remote-control centre supported by novel technology (DNV, 2018b, p. 9).

DNV class guideline (2018) gives also guidance to the technical arrangements in remote-control centre to facilitate remote-control and supervision of vessel functions. The guideline uses different categorizations for the degrees of automation for the navigation functions and the engineering functions. New operational concepts are introduced based on technologies that are still under development. Technology modules may be combined to support new operational concepts. (DNV, 2018a, p. 25).

Standards, guidelines and best practises seem to have a common goal to ensure and give guidance for safe, secure and efficient autonomous or remote-operated vessels and control systems. Several publications are referring to each other and definitions and practises are overlapping; however, they are generally in line with each other. The standards, guidelines and best practise documents include altogether numerous items that may be considered as initial design requirements for the remote-control system. Because of the quantity of items, only most suitable of the standards, guidelines and best practises are referred in the thesis.

4.4 Navigation

Navigation can be defined as “all tasks that are relevant for deciding, executing and maintaining the course and speed of a vessel in relation to waters and traffic” (Babicz, 2015). According to DNV GL class guideline (DNV 2018a), the list of potential autoremote functions include functions that may be subject to a high level of automation and remote-control. The list includes navigation, engineering, other functions and special operations.

Navigation functions are interlinked to four general ship functions, condition detection, condition analysis, action planning and action control. The following list of functions may not be exhaustive but can be used as a basis to support Goal-Directed Task Analysis. According to DNV class guidelines, potential navigation autoremote functions include as follows:

1. Planning of the voyage and route.
2. Determining of ship safety relevant data: position, course and speed, follow route, keep general lookout and determine CPA and TCPA for potential navigational dangers and other ships.
3. Monitoring of depth, sea-state, tide, current, weather, visibility, seakeeping performance and distress signals.
4. Determining the situational mode (e.g. unrestricted, dense traffic, costal navigation, narrow passage, restricted visibility, heavy weather, very cold weather, ice conditions, pilot required).
5. Docking, undocking and manoeuvring.
6. Controlling of propulsion and steering, grounding and collision avoidance
7. Weather routing.
8. Communicating with other vessels and with shore (e.g. notice to mariners, vessel traffic service, weather forecast, rescue services, pilot services, etc.).
9. Controlling navigation lights and sound signals.
10. Supervising bridge-related systems, ship's state and operational capabilities. (DNV, 2018a, p. 96).

For a ship to be navigated safely, any element that can affect the navigation must be detected early enough that it can be controlled in a safe and secure manner. Elements include geography, bathymetry, fixed objects, floating objects, weather conditions and conditions of the ship which may potentially affect vessel´s manoeuvrability. Condition detection is conducted by a combination of information, sensors and people. In unmanned operations the on-board sensors must replace the senses of the on-board navigators and detected information must be collected and used to analyse the condition of the ship in the RCC. Adequate situational awareness will require that all detected objects or conditions are classified and changes are established in order to define near future states of systems and environment. Classification must be carried out by an algorithm on autonomous vessels or the operators in RCC. Sufficient information must be transferred from the sensors to the RCC in a timely manner that gives requirements for type, volume and latency of information transmitted and the way it is presented to the remote operators. The operators´ ability to perceive the situation correctly and perform proper action depends on the type, quality and integrity of presented information. (DNV, 2018b, p. 6-12).

Remote-controlled condition analysis is conducted by the remote operators in the RCC. Sufficient information must be transferred from on-board sensors to the RCC in a correct time. The information needs to be presented in a way that supports the operators’ cognitive abilities. The operators need focused view with only a few top-level indicators and access to system status information in order to assess the situation correctly. When the USV is operating near the shore or coast they can use radios and mobile systems. Requirements for data transfer capacity may be reduced by decreasing transmitted raw data parameters such as field of view, resolution, and colour depth or frame rate. Pre-processing the information before transmission and post-processing the information probably takes place in RCC. (DNV, 2018b, p. 9-10).

After conditions are analysed and sufficient situation awareness achieved in SA level 1 and 2, the course of action must be planned. A pre-defined mission plan is based on analysis and prescribed rules such as the COLREGs. Planning and decisions will be carried out by the remote operators. The operators can make direct decisions based on the situation awareness on SA level 1 and 2 or evaluate decisions made by an algorithm in a decision support. The final decision will be a result of the operators´ assessment. This determines requirements on how condition analysis is presented and the operators´ performance based on SA levels 1-3. When actions are planned, the operators must decide how navigational and other decisions are executed using propulsion systems and rudders. The control command is given by the remote operators using remote-control systems. The control systems must ensure that the resulting manoeuvring is in accordance with the control input. Reliability of the action control will depend on the reliability of the communications between the remote-control system and the vessel. (DNV, 2018b, p. 6-12).

4.5 Monitoring and controlling

Monitoring and controlling are the two fundamental tasks of the remote-control system. According to Maritime UK (2021), remote monitoring means monitoring some or all ship operations or functions at location outside the vessel. Ensuring the safety of the mission shall enabled by the design of remote-control system manning, task allocation, workload and system design. The situation awareness and control systems shall be designed to ensure the operators´ continuous monitoring and ability to stay in the loop continuously. The design shall ensure safe controlling of navigation and payload control at all times. System and software designers shall also ensure the design of efficient communication between the RCC operators as well as data transfer between the remote-control system and the USV. (EDA, 2018, p. 5-8).

4.5.1 Monitoring

According to Merriam-Webster dictionary (2020) to monitor means “to watch, keep track of, or check usually for a special purpose”. For monitoring the remote-control system operators need information or data to monitor. That information or data is provided mainly by sensors and systems from the USV and presented by the operation management system or remote-control system that enables the situation awareness for the operators. Monitoring is conducted typically by observing visual displays, audible data and in some cases sensing haptic feedback from the sensor such as accelerometers. The operators make perceptions based on their observations (SA level 1 perception), try to comprehend the current situation (SA level 2 comprehension) and use perception and comprehension to determine a projection what happens next in the near future (SA level 3 projection of the future status). Successful conduct of monitoring is therefore essential for decision-making and controlling actions. Adequate monitoring is a cognitive task that combine a lot of visual, audible, linguistic and sensing of haptic information. In that sense it is essential that the operation system provide monitoring data for the operators optimised regarding quality, reliability, time, environment and situation based on human factors principles to enable safe and effective controlling.

Vessels systems or the remote operators must monitor the vicinity of the USV and other vessels in order to avoid collisions and groundings. Maritime radars are able to detect objects further away from the vessel, but small and low targets near the vessel may remain undetected by the radar and seeing them is often based on human observation. Video and thermal cameras, laser and close proximity scanners are examples of devices that produce information on the vessel´s vicinity. The amount of data generated by several devices may be large and cause problems in data transfer between the USV and RCC. Processing and compressing collected data and AI solutions related to classification and identification of objects are currently in research fields to sensor technology. (Aboa Mare, 2018, p. 15-17).

Besides navigation functions, the RCC systems or the operators are required to monitor engineering and other vessel autoremote functions. Engineering functions include overall supervision of machinery-related systems, machinery control and monitoring, electrical power generation and distribution, fuel management and battery charging controlling and monitoring. Other vessel functions include controlling of shell-doors and watertight doors and monitoring of stability, bilge and drainage, HVAC, mooring, unmooring, anchoring, fire detection, firefighting and logging of data and events. Special operations may include keeping dynamic positioning, fire-fighting, search and rescue operations and damage control. (DNV, 2018a, p. 96-97).

According to Ahvenjärvi (2016), failure to monitor adequately may occur when something is perceived to fail and the operators feel like a must to intervene. Automation intervention failures originate usually from three sources related to detection, situation awareness and skill loss. Experienced operator will likely be slower to detect real failure. The operators are better aware of the dynamic state of the processes in which they are active participants The operators may experience to be inactive perceivers, decision-makers or controllers that can cause the operators to become less self-confident and relaying to the automation even when they should take over the control of the system. The operators´ ability to intervene in a proper manner may also degrade if the system fails. The HMI in the RCC should be developed using decision-making approach that supports the operators’ ability to establish and maintain high level of situation awareness and remain “in the loop”. It is critical to use user-centred design methods to develop safe remote operations for autonomous and unmanned ships.

4.5.2 Controlling

Control is a significant mechanism for achieving safe operations in unmanned systems. When systems are controlled remotely, the unmanned vehicles and control systems may be in separate locations and required communication for interaction between the vessel and control systems may cause delays or errors. Controlling functions can be allocated to the human operators or to an on-board software based functions. Interaction between the operators and the systems can range from full control to a monitoring role. (EDA, 2018, p. 5-8). Remote-control means operational control of some or all ship functions, at a remote place away from the ship. A controller is a person that undertakes control functions. Controller may report to a watch officer or the master depending on the constitution of the control function, the MASS category and the required level of control. (Maritime UK, 2021, p. 18-21).

Controlling of a ship function can be divided into four main parts. Detection includes acquisition of information that is relevant for control. The information may be based on sensors or the human operator´s perceptions. Analysis consist of interpretation of the acquired information and situational understanding relevant for control. Planning includes determination of needed changes in control parameters in order to keep the performance within planned level. Action means execution of planned changes of control parameters, usually by a control system. (DNV, 2018a, p. 52).

According to LR Design and Construction Code, the control system includes any systems on-board the unmanned vessel and off-board facilities that perform monitoring and controlling of propulsion, manoeuvring and navigation systems as well as transmission of data to execute these functions. The goal of the control system is that the system shall be designed with a level of integrity sufficient to enable the USV to be operated and maintained safely in all reasonably foreseeable operating conditions. (LR, 2017, p. 12).

According to Endsley and Jones (2011), there are at least four different classes of control of the unmanned vehicles. In exocentric teleoperation control, the operators have direct line of sight to the vehicle as it moves through the water or air. The operators control the path of the vehicle and its parameters (speed, course, camera motion) directly. In egocentric teleoperation, the operators' don´t have direct line of sight and control the vehicle through camera views that show what is seen out of the window of the vehicle. This type of control typically tries to duplicate the experience of the pilot or driver of a manned vehicle. When automation is allocated to be responsible for some parts of the operators tasks (trajectory, course or other system operations), an egocentric semi-automated or automated control is executed. Control modes may change depending on the control mode and level of control.

The remote operators are required to have sufficient situation awareness in order to be able to execute the control tasks adequately. It is crucial, that the operators are presented as real-time data as possible regarding at least the critical statuses of USV systems. The systems include at least the position, course, speed, near vicinity traffic, obstacles, hazards, terrain and other risks as well as relevant environmental data such as weather, wind, temperature, humidity and ice conditions. For controlling tasks, the operators need actual controls of the ship. These may be for example hardware of software based levers, thrusters, mini wheels, rudders, joysticks or other means of controlling vessel´s engines, propulsion system or course and speed. Reliable and cyber secure data transfer capability and arrangements are required to provide reliable and time accurate situational data from the USV to the control system and enable efficient sending of control commands to the USV.

In the RCC the requirements for reliability, availability and fault tolerance of the control system and actuators are probably higher than in manned ships. Reliability must be ensured by requirements to the design and testing during production. Autonomous and remote-controlled arrangements can support and supplement each other and act as redundancy. A combination of the remote operators´ cognitive performance and algorithms shall handle situational awareness and decision-making efficiently. Autonomous system shall provide control of the ship in case of connectivity lack or loss. System shall be able to abort normal operations and enforce the vessel in safe state or a minimum risk condition (MRC). Control of MRC must be automated and initiated based on a threshold risk for normal operation. (DNV, 2018b, p. 23-24) The remote-control system shall be capable of controlling of the USV using all control methods from 0 to 5. The requirements and guidelines to the interfaces and software design shall enable the control of USV operations using manual, remote-control, directed, delegated, monitored or autonomous methods. The operated method is depending on the capabilities of USV´s system on-board and the operational environment, situation, tasks and manning of the remote operation module system.

4.6 Summary

A remote-control centre is an operative monitoring and control centre for the autonomous or remotely operated unmanned vessels. The two fundamental tasks of the remote-control centre are monitoring, sustaining the situation awareness of the vessel and its environment, making time accurate and correct decisions. When required, the RCC will take over control of the unmanned vessel effectively, efficiently, safely and securely. One of the main challenges in remote-control centre seems to be keeping the remote operators´ situation awareness on an adequate level when they work outside the vessel on a shore-based facility or on-board another ship.

Some of the standards, guidelines and best practises described in Chapter 4 regulate, guide and frame tasks and functions of remote-control centre. There are numerous items in the standards and guidelines that shall be applied in the design of safe and secure remote-control system. Guidelines and best practises may not be actual requirements; however, design of the remote-control system shall comply with provided standards, guidelines or best practises when they are seen feasible and executable in practise. Sub-tasks of navigation function such as condition detection, condition analysis, action planning and action control, as well as navigation autoremote functions are further analysed in Goal-Directed Task Analysis.

In the RCC, monitored information and data are mainly provided by sensors and systems from the USV and presented to the operators by the system that enables adequate situation awareness. Systems shall ensure that the operators perceive and comprehend the information in a correct manner. Projection of the future status of all ship and remote operated systems as well as what happens in the environment and vicinity of the vessel on an adequate level is mandatory for safe operations. Successful conduct of monitoring is essential for decision-making and controlling actions.

Controlling is a significant mechanism for executing safe operations with unmanned systems. Controlling means taking over control functions according to the level of control defined for the situation in order to affect the desired action. Controlling a ship usually means operating the devices related to navigation and other operations. Taking over control requires cognitive process of decision-making. Decision-making shall be supported by adequate situation awareness. Levels of control and control task allocation between the human operator and USV depend on the system configuration, tasks of the system and may vary during the mission.

5 Human factors guidelines and principles

Chapter 5 contributes to the fourth research question, “What are system requirements for a remote-control system from user-centred perspective?” from human factors point of view by reviewing human factors literature and research. According to Endsley and Jones (2011), user-centred design integrates information to goals, tasks and needs for the user and provides means to deploy information technology to support the human operators´ work. Principles for user-centred design include organising technology to support users´ goals, tasks and abilities and the way they process information and make decisions. Technology keeps users in control and aware of the state of the system. Situation awareness is a key to user–centred design.

Multiple sensors are used for monitoring and controlling operations resulting in increased amount of information provided for the operators. Data fusion is proposed to avoid the risk of information overload that may reduce SA and execution of efficient control. The design of ergonomics of monitoring and controlling systems takes into account the human vigilance. Vigilance may occur during extended periods of remote-control or when several ships which are in different situations are managed by only one operator at the same time. The system design must ensure that the remote operators are aware of the latency of the data transfer that may cause a delays between the operators´ control commands and the USV reactions. The latency should be continuously displayed to the operators during the operations, for example warnings or alerts should be provided when the latency is over pre-defined limits. (BV, 2019, p. 15).

5.1 Design principles that support situation awareness

Design principles that support situation awareness include guidelines to present information to the operators, support projection, provide global situation awareness and support data-processing. Design requirements for the remote-control system that are derived from the design principles are presented in *Italics*. Endsley and Jones (2011) explain that the way information is presented to the operators through the interface influences situation awareness by determining how much information can be acquired in the available time. The objective of the interface design is to create system interfaces that transmit needed information to the operators as quickly as possible without unnecessary cognitive effort. (Endsley & Jones, 2011, p. 79). *The remote-control system shall provide information presented around the operators´ goals.*

Attention and working memory are limited, therefore displays should provide information that supports understanding in order to increase comprehension on SA level 2. Displaying the deviation between a current value and its expected or required value is better than requiring the operator to calculate this information based on perception of information on SA level 1. SA level 2 requirements include prioritisation, unity between data values, requirements and affect the operators´ goals. In some cases, SA level 2 information (what is really needed) and SA level 1 data (lower level information) may not be required and sometimes both levels l and 2 data are important for building complete situation awareness. Human-centred approach presents the information the operators really need in terms of integrated SA level 2 data. (Endsley & Jones, 2011, p. 81). *The remote-control system provide information that supports comprehension.*

Projection of the future states of the system on SA level 3 is one of the most difficult parts of situation awareness. Projection requires a well-developed mental model. System-generated support for projecting future events and states of the system directly benefits SA level 3. A trend display or graphing changes in a parameter over time can support the operators to project future changes in that parameter. Displays that allow the operators to anticipate possible occurrences can support the operators´ ability to create projections. (Endsley & Jones, 2011, p. 81). *The remote-control system shall provide information in format that supports projection of future state.*

Global situation awareness, a high level overview of the situation across the operators´ goals, shall always be provided. Detailed information related to the operators´ current goals should be provided simultaneously. A global SA display that is visible at all times is required, since global SA is critical for prioritisation of goals enabling projection of future events. (Endsley & Jones, 2011, p. 81-82). *The remote-control system shall provide information in format that supports global situation awareness.*

Designing the system around the operators´ goals supports goal-driven processing. The big picture display that supports global SA supports data-driven processing by directing the operators where to focus attention to achieve high priority goals. The key factor is to ensure that these two approaches complement each other. (Endsley & Jones, 2011, p. 81-82). *The remote-control system shall provide information in format that supports both goal-driven and data-driven processing.*

Mental models and schemata are key features for achieving the higher levels of SA. Critical cues used for activating mental models and schemata must be determined in the interface design. Determining critical cues shall be coded on the display with essential cueing that supports the operators´ decision-making. (Endsley & Jones, 2011, p. 83). *The remote-control system design shall determine critical cues based on the operators' goals and the system shall provide critical cues of information that supports the operators´ decision-making.*

The operators can visually take in a limited amount of information; however, the operators can process tactile information simultaneously with auditory and visual information, since they require different cognitive resources. Auditory displays convey spatial information in ways that do not load the operators´ visual channel. (Endsley & Jones, 2011, p. 81-82). *The remote-control system shall provide information in format that supports parallel information processing.*

The problem of information overload must be considered by information filtering. Filtering aims to support SA and reduce data overload, but may remove global SA the operators need to be proactive and predictive. The operators' ability to develop SA on system dynamics and trends may be compromised as they may not understand how the system is changing over time when information is filtered. (Endsley & Jones, 2011, p. 83-84). *The remote-control system shall provide information in format that supports dynamic information filtering.*

5.2 Guidelines for human centred system design

Human centred system design includes guidelines to support selective attention, perception and working memory, improving decision-making, situation awareness, planning and scheduling. Design requirements for the remote-control system that are derived from the design guidelines are presented in *Italics.*

According to Lee et al. (2017), design of the system shall maximise bottom-up processing of information by increasing visibility, legibility and audibility of sounds and avoid message sets that can cause confusion when presented in the same context. The design shall maximise automaticity and unitisation by using familiar information such as standardized or consistent terminology, fonts, icons and symbols. The design shall maximise top-down processing of information by displaying important information in a consistent location providing the best possibility to anticipate where the information can be found. (Lee et al., 2017, p. 170-172). *The design shall optimise bottom-up processing of information, automaticity, unitisation and top-down processing of information.*

The working memory capacity is limited. Systems that require use of working memory for more than three items for more than seven seconds or one item for more than 70 seconds are likely to cause errors. The system design shall minimise the operators´ working memory load by avoiding long codes of random digits or numerical chains and provide visual displays for redundancy when using auditory presentation and provide display audible alerts simultaneously as text on a tactical display. Information should be divided to meaningful parts, words and letters should be made to sound and look different by spatial separation between information. (Lee et al., 2017, p. 176-178). *The remote-control system shall provide information in format that supports working memory.*

Decision-making may be improved by task design and creating systems with greater stability. The number of options should be limited to four or five options because too many options increase pressure on the decision-maker. The operators often choose default options, therefore selecting useful defaults may improve decision-making. Predictive defaults are valuable especially in highly integrated systems. The operators are more likely to choose defaults if they first have to select an option from many choices. (Lee et al., 2017, p. 223-225). *The remote-control system shall provide information in format that improves decision-making including default values determined by the requirements of goals.*

Procedures and checklists can make decisions more consistent and accurate. Decision tables list the possible outcomes, probabilities and values of the action alternatives. The decision-maker enters estimated probabilities and values into the table and computers calculate and display the utilities for each possible choice. A decision table reduces the operators´ working-memory load. (Lee et al., 2017, p. 225). *The remote-control system shall include operational procedures and checklists including corrective and preventive actions and emergency situations*.

Displays shall support the operators to perceive changes by highlighting them to the operators (SA level 1). The situation shall be made easy to understand (SA level 2) by presenting information about the state of the system relative to the operators´ goals instead of requiring that operators interpret and mentally combine information. The design shall keep the operators “in the loop”. The operators are more likely to remember actions and the consequence of actions, if they have generated the action themselves. The operators shall be supported to project the state of the system into the future (SA level 3) by designing displays that show the future state. Predictive displays relieve the operators of mentally simulating and projecting future states. Displays shall be designed to cluster information according to the goals the operators are trying to achieve. (Lee et al., 2017, p. 230-231). *The remote-control system shall improve situation awareness by displaying changes and status around goals and include future state predictions.*

The operators´ limitations in planning and scheduling can be supported with automation. Plans need to be revised as the situation evolves and unexpected events occur. The design can support creating of contingency plans and planning to re-plan. Predictive displays that offer visual representations of the likely future may reduce the need for working memory and are effective automation tools to reduce cognitive demands in planning. (Lee et al., 2017, p. 235). *The remote-control system shall include planning and simulation tools to support contingency planning and scheduling.*

5.3 Summary

Human factors literature provide a wide variety of design principles for user-centred design. Feasible user-centred system design principles and guidelines selected for the remote-control system design requirements are presented in Chapter 5. These principles are not actual requirements; however, they must be taken into account when designing a system from user-centred perspective.

Design that supports the operators´ situation awareness includes that at least the crucial information is presented alongside the operators´ goals. This information may vary depending on the operators´ goals that may change over time of the conducted mission therefore, the display system must be adaptive to changes. Presenting information that supports comprehension and projection of a future state may seem to be self-evident; however, technical solutions need to be carefully designed, since a system must be able ensure that the operators conduct safe and efficient operations. Adequate situation awareness is built on factors that enable the operators to understand the situation correctly and predict or anticipate what happens next in a sufficient way thereby making pro-active measures possible.

A global SA display that is visible at all times supports the operators´ situation awareness and decision-making. Supporting the operators´ information processing and decision-making by means of supporting mental models and schemata are key features for achieving the higher levels of SA. Dynamic information filtering can support preventing data overflow. Human centred system design optimises bottom-up processing of information, automaticity, unitization and top-down processing of information. The system shall present the information in a format that supports the operators´ working memory taking into account the limitations of it. The operators´ decision-making shall be improved by including default values determined by the requirements of the operator’s goals. The system design shall utilise and include adequate operational procedures and checklists including corrective and preventive actions and emergency situations. The operator’s situation awareness shall be improved by displaying changes and status around the operator’s goals and include future state predictions. Including planning and simulation tools to the system design shall support the operator’s contingency planning and scheduling.

6 Operated systems

Chapter 6 answers the second research question, “What are the remote operated systems?” by reviewing operated systems. The operated systems in this thesis include the operation management, navigation and unmanned vessel systems. Some design requirements for the remote-control system that are derived from the system descriptions are presented in *Italics.*

6.1 Operation management system

Merriam-Webster dictionary (2020) defines an operation as “a performance of a practical work or of something involving the practical application of principles or processes and management means the act or skill of controlling and making decisions”. Operating the USV systems in this context is conducted from the remote-control system located on-board a mother ship. The remote-control system is part of an operation management system (OMS), which is a host system and provides information and data enabling high level of situation awareness for the remote operators. Three essential functions that the OMS and the remote-control system must perform in order to successfully accomplish the goals and tasks are mission planning, execution and evaluation. The OMS´s command and control module is required to produce a plan based on the mission objectives and tasks. The command and control module shall enable setting of mission parameters and measure conduct of the tasks including a performance indicator that can provide predictions on the mission proceeding. *The remote-control system shall display and provide monitoring and controlling of the USV systems during execution of the tasks. Additionally, the system shall provide visual, audible and haptic feedback to the operators enabling minimal delays of remote-controlled functions along with tools to conduct mission evaluation.*

The OMS is an integration platform for operation system sensors, effectors and sub-systems enabling the centralized use of all integrated system components. The OMS supports the integration of sensors, effectors and sub-systems to form one operation system. Sensors and effectors can be either fully integrated or partially integrated to the OMS. Fully integrated means that the sensors or effectors are fully under OMS control. Controlling of sensors and effectors are in this case part of the OMS HMI and the systems exchange data on a dedicated data interface. Partially integrated means that the sensors or effectors are used from the system´s own HMI either from a dedicated console or as a remote HMI. (AEFI 2021, p.10).

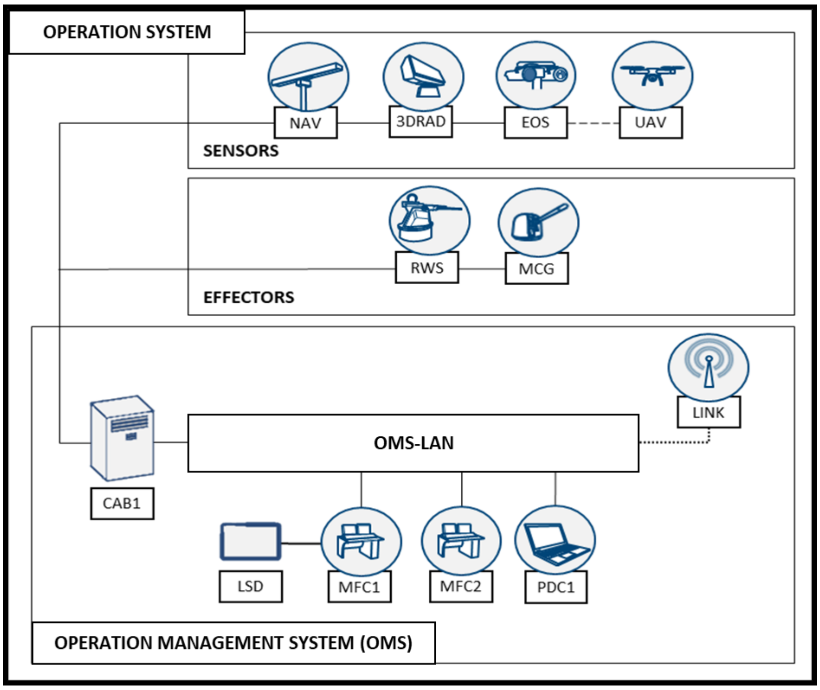

Figure 11: A simplified example of a typical OMS configuration (AEFI, 2021, p. 10).

The situation awareness functionality in the OMS includes at least track management, tactical areas, observations, notes, warnings and alerts. SA is established by presenting known information on an electronic display (map) in real-time. The presented information includes own units, targets originating from own sensors, radar video, electro-optical sensor video, observations, relations between objects on the map, plans and active tasks and their statuses. Additionally, the information includes weather and other environmental data, routes and maximum ranges of sensors and effectors. (AEFI, 2021, p. 10). *The remote-control system shall utilise OMS situation awareness capabilities and tools.*

The command and control functions in the OMS provides planning, commanding and controlling tools. Planning function includes the objectives of the mission or the operation and a sequence of tasks to achieve the objectives. Commanding function provides tools for commanding and controlling the sub-ordinate units and contains assigning the tasks to the executing units. Controlling function includes controlling the tasks statuses, receiving reports from the executing units and updating the statuses of the plans accordingly. (AEFI, 2021, p. 15). *The remote-control system utilise OMS command and control capabilities and tools.*

6.2 Navigation system

6.2.1 System description

A navigation system contains functions for collecting and receiving data from navigation sensors. The data contains at least a position of the vessel, speed, heading, roll and pitch angles and corresponding angular rates. Additionally, the system includes functions for distributing the navigation data to connected users and systems and controlling and displaying facilities for system operation and indicating the navigation data. The integrated bridge and navigation system provides safe operations and controlling of necessary navigation functions, sensors and electronic navigation aids including multi-function workstations displays. A navigation system consist of a variety of sensors that provide information and contribute to overall view. Selectable information can be displayed on several displays. The navigation sensors of the integrated navigation system use standardised interfaces and formats. The layout of the integrated navigation system and the interconnection between the system components depend on the ship type and size. A navigation system is usually a combination of the commercial off-the-shelf information technology hardware and software in order to fulfil the relevant standards, rules and regulations of the IMO Standards. (Furuno Finland, 2021a and 2021b).

An integrated navigation system can support remote operations by indicating operation modes and navigation data of the selected sensors such as a position of the vessel, heading, speed, roll, pitch, angular rates and depth. The system may also include alarming functions for system faults and controlling and displaying the inertial navigation system, meteorological information, video surveillance (CCTV-system), automatic information system data and electronic chart display and information system functionalities. An integrated navigation system is usually an open system allowing system expansion, upgrading and additions of sensors. (Furuno Finland, 2021a and 2021b; Kongsberg, 2021).

According to Det Norske Veritas (2018b), the sensors must detect objects critical to the navigational safety of the ship and its surroundings in all feasible ambient conditions. The position of the vessel in a navigation scenario is critical for safe operation. At the moment, there is a significant reliance on Global Navigation Satellite System (GNSS), therefore loss of the GNSS signal will be critical to operations in RCC without an attending crew on-board the vessel. The sensors are required to assess the capability of propulsion and steering at all times and predicting changes in this capability. This assessment is conducted by sensor-based condition monitoring of all the critical components. The reliability of sensor signals must be maintained during the operation. Homogeneous redundancy is achieved by two or more sensors measuring the same quantity; heterogeneous redundancy is when a system is instrumented with several sensors measuring different quantities. It provides redundancy because the failure of one sensor may be remedied by calculating this quantity based on the readings from the other sensors. (DNV, 2018b, p. 6-12).

Navigation system equipment consist for example of the bridge system, consoles, compass monitoring and navigation data distribution system. The system typically includes heading and bearing repeater systems, an electromagnetic speed log, depth sounders, a Differential Global Positioning Systems (DGPS), an Automatic Identification System (AIS), an Electronic Chart Display and Information Systems (ECDIS) and radar systems (S-band and or X-band). The navigation system may also contain a meteorological system, a time system, magnetic and gyro compass systems, inertial heading and attitude systems, search and signal lights, voyage data recorder and CCTV-systems. (Furuno Finland, 2021a and 2021b; Kongsberg, 2021). The navigation system is usually network-based, remote-controlled and integrated with the multi-function consoles. The Global Maritime Distress and Safety System (GMDSS) positioning system provides data regarding the own ship, such as a geographical position, speed and course over ground and time. (Furuno Finland, 2021a, 2021b; Kongsberg, 2021). An inertial navigation system contributes to significantly improved performance and accuracy. The inertial system provides heading and pitch and roll angles, angular rates, acceleration, velocities and position and heave in digital format. A meteorological system provides information such as relative wind, true wind, air temperature, humidity and dew point temperature and barometric pressure. A voyage data recorder system is required to be fulfilling IMO and IEC standards. (Furuno Finland, 2021a and 2021b; Kongsberg, 2021).

The navigation functions consist typically of display of own ship´s navigation data and environmental data. Own ship´s manoeuvring support function includes calculation of recommended heading and speed values for a given course and speed over ground information and environmental conditions like wind force and sea current influences on the motion of own ship. The navigation system may include automatic navigation features or sub-systems such as track control system including autopilot and ECDIS. Track control system steers the vessel automatically along pre-defined route and warns the remote operator before turning the vessel. The operators may approve suggested turning sequence or the automatic system may turn the vessel by itself depending the level of autonomy. A complete automatic navigation system (ANS) is designed for autonomous USVs. The ANS is composed of a path planning subsystem (PPS) and a collision avoidance subsystem (CAS) to ensure that a fully-autonomous USV travels in a realistic sea environment. (Sun et al., 2018, p. 1-2).

6.2.2 Example of an integrated bridge system

Furuno Finland's integrated bridge systems´ (IBS) basic configuration is typically implemented using radars, ECDIS and other sensors. The IBS-solution may consist of an integrated conning, a track pilot, an AIS, an autopilot, a Doppler-log and GPS and alarm systems as well as a chart plotter, a compass system, navigation software, multifunction displays, a weather fax, radars and a voyage data recorder. (Furuno Finland, 2021a).

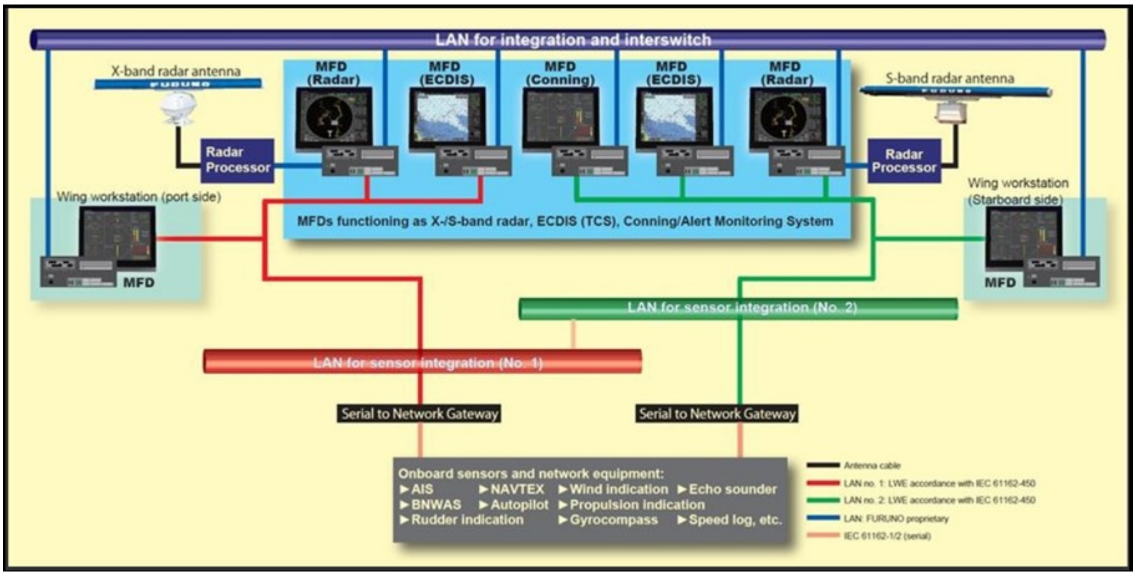

Figure 12: An example of devices and connections on an integrated bridge. (Furuno Finland, 2021a).

6.2.3 Unmanned Vessel´s Navigation System

When an USV is operated remotely, the information from the navigation and surveillance sensors is transferred from the vessel to the remote-control system to maintain the situation picture. In the Furuno´s system solution, the centre of the navigation system is a map device, which integrates Doppler pulse compression radar and a thermal camera that can be used from the remote-control system. (Furuno Finland, 2018).

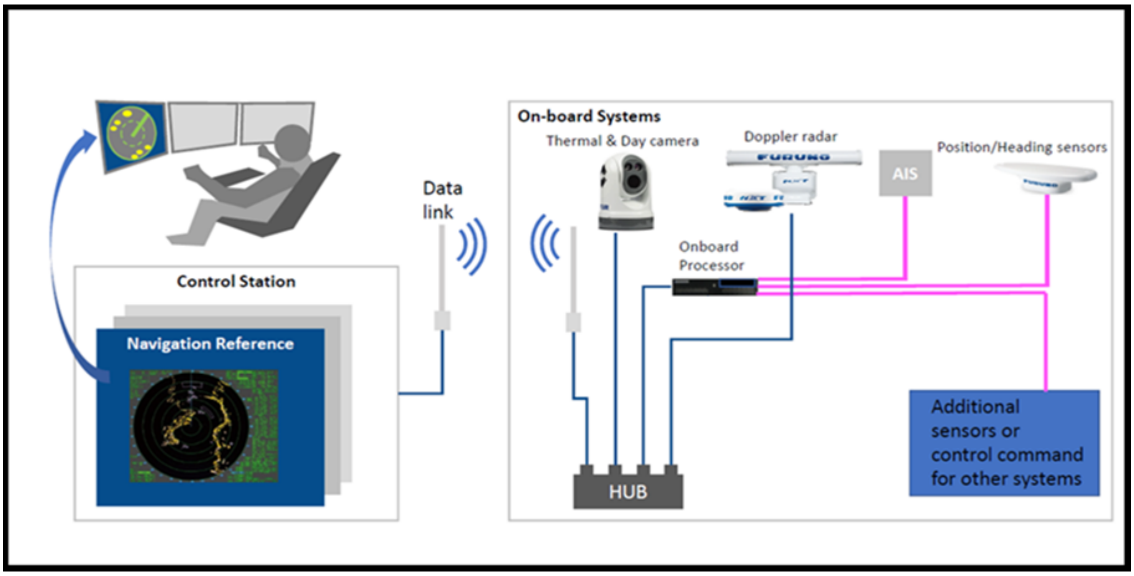

Figure 13: The operating principle of the USV solution (Furuno Finland, 2018).

According to EDA (2018), an USV and controlling entities shall be designed, handled and operated to ensure safe and predictable navigation and avoid hazardous situations and collision. Situation awareness regarding collision avoidance is focused on close proximity of the USV. A sense and avoid (SAA) system aims to ensure that the USV remains clear and avoids collisions with other traffic and objects. Sense and avoid system typically provides functions of self-separation and collision avoidance. EDA (2018) defines regulations for sense and avoid and situation awareness that should be considered to achieve a safe unmanned system. Without direct human control of a system, the USV sensors and systems must gather and present data to enable efficient controlling. The system shall have an acceptable method to sense and assess the situation in order to avoid collisions. Collision avoidance requires adequate means, methods and systems to assess the situation and sense and avoid hazards on an efficient manner. The USV operations beyond the direct unaided visual line-of-sight of a controller should only be performed with an USV equipped with a sense and avoid system of adequate performance. (EDA, 2018, p. 33-35).

The USV may be equipped with intelligent navigation support system such as a SAA-system that is COLREGs aware (AEUK, 2021) or Sounder K-MATE autonomy system that provides safe navigation and control of the system capable of direct remote-control, supervised or autonomous operation (Kongsberg, 2019). Intelligent navigation support systems are designed to be compliant with or aware of current legislation; however, even in that case they can´t take in to account all scenarios and outcomes of them and therefore usually requires real-time supervision by the human operators´ in order to enable safe operations. The decision-making regarding information or approval of actions recommended by K-MATE SAA-system remains as the responsibility of the human operator in the supervision role, in other words as the responsibility of the remote-control system operators.

6.3 Unmanned surface vessel systems

Unmanned Maritime System (UMS) is defined by NATO as "an unmanned system operating in the maritime environment (subsurface, surface, air) with at least one primary component as unmanned vehicle" (NATO, 2012, p. VI). Functional objectives of the UMS system include ability to monitor and control all systems required for propulsion, manoeuvring and navigation (LR, 2017, p. 12).

6.3.1 Unmanned maritime surface vessels

According to Endsley and Jones (2011), the term unmanned means uninhabited; however, a human operator of some sort exists, even if he or she is not on-board the vessel. The operators are an important component of the system and have the same needs for situation awareness as they would if they were on-board. The challenges for gaining and maintaining SA are significantly greater in the RCC than on-board a vessel due to remote status of the RCC. NATO defines an USV as "a self-propelled surface vehicle whose operation is either fully autonomous or under minimal supervisory control". The foreseen future capability requirements for unmanned ships are intelligence, surveillance and reconnaissance (ISR), cheaper systems, lower risk to personnel, less vulnerable to cyber-attacks, stealth and less collateral damage. Military missions that could be executed by an USV are maritime security, mine countermeasures, anti-submarine, surface and electronic warfare, support for maritime interdiction operations and special operations. (NATO, 2012, p. VI-VII).

The unmanned maritime system´s components consist of an unmanned vessel or vehicle, a control system, a support system and personnel. The unmanned vessel´s waterborne parts include the platform and mission equipment. (EDA, 2018, p. 3). An unmanned vessel is without a crew or personnel on-board. The vessel may be unmanned for the trans-oceanic phase of a voyage. An unmanned ship is not necessarily autonomous. The vessel may be remotely monitored and controlled from a RCC receiving information e.g. via satellites. The RCC has the ability to take remote-control if required or if in doubt of the autonomous system. (Porathe, Prison & Man, 2014). The unmanned marine system must be safe, dependable, capable and resilient in all reasonably foreseeable operating conditions. (LR, 2017, p. 1). This is understood to consider all systems on-board the vessel and in the remote-control system.

6.3.2 Vessel systems

EDA (2018) breakdown structure explains that the UMS system includes basically a platform and a control system. Platform system is divided to vehicle and mission equipment. A control system contains mission planning, control and evaluation systems. (EDA, 2018, p. A2-1).

Name	Description of content examples
USV vessel	Structures, propulsion, energy supply, auxiliary machinery, electrical, vehicle control, fire and explosion protection and communication systems.
Structures	Hull and deck, equipment support and bracket, launch and recovery interface, docking Interface and mooring interface.
Propulsion	Primary mover (electric motor or combustion engine) and drivetrain systems (shaft, propeller, water jet or pump jet).
Energy Supply	Energy (battery, battery management), liquid fuel energy (fuel tank, metering and management) and energy management systems.
Auxiliary Machinery	Compressed air, hydraulic, ventilation, piping and duct systems.
Electrical	Main and emergency power supply, power control and distribution systems.
Vehicle Control	Vehicle control (on board computer and control software), vehicle dynamics (pitch, roll, yaw), position and navigation (GPS, DVL, depth sensor, compass) and situation awareness sensors (radar, sonar, proximity sensor), autopilot, navigation, dynamic control actuator (rudder, thruster) and displacement control systems.
Fire and explosion protection	Fire detection (smoke, heat and gas sensors) and firefighting systems (CO2, halon extinguishers or sprinklers).
Communication	Radio communication (VHF, UHF), satellite communication (IRIDIUM), hydro acoustic communication and local communication systems (W-LAN).
Mission Equipment	Sensors, effectors, communication and launch and recovery systems for payload. Sensor system may include surface and air sensors (radar, ESM, IR-camera, LIDAR, visual Camera), sub-surface sensors (sonar, echo sounder), surface environmental sensors (temp, gas, radioactivity), sub- surface environmental sensors (temp, salinity, chemical substances), anti-air weapon systems (gun, missile), anti-surface weapon system (gun, missiles, torpedo), anti-submarine weapon system (depth charge, torpedo, ASW-rocket), messaging system (speaker, strobe light, flare), soft kill weapon system (high pressure water gun, loud noise emitter), countermeasures system (decoy, jammer).

Table 3: The unmanned maritime system of systems (EDA, 2018, p. A2-1).

6.3.3 Examples of unmanned surface vessels

Israel Aerospace Industries´ Katana system can be used as a remotely operated or an autonomous USV or as a manned vessel depending on the mission requirements. Katana is planned to conduct homeland and harbour security, patrolling, surveillance, intelligence, firefighting, search and rescue, resource protection, fleet defence, special forces, mine-counter-measure and anti-submarine-warfare operations. The Katana USV system enables remote operations of payloads and includes a command and control system for remote operations. The system is operated typically by two operators and a mission commander. The command and control system functionalities include mobile standalone control system with advanced command, control and communications capabilities and collision and obstacle avoidance systems. Katana systems provide autonomous navigation and functionalities for mission planning, controlling, recording and debriefing as well as remote-controlling. (Israel Aerospace Industries, 2021).

The collision and obstacle avoidance system aims to ensure safety of the autonomous vessel by minimising the risk of collisions at sea. The line of sight (LOS) and non-line of sight (NLOS) data communication links provide secure communication over long ranges. The maritime radar allows the vessel to obtain early-warning situation picture of the targets. The electro-optical and thermal cameras provide improved observation and surveillance capabilities. Daylight and night-vision camera systems offer a 360° video panoramic view, clustered or distributed configurations, motion detection and video record playback capabilities. The system provides interfaces to remote-controlled weapon systems. (Israel Aerospace Industries, 2021).

The collision and obstacle avoidance system recognizes typical maritime obstacles including other watercraft, fixed structures, buoys and marine life. The system will autonomously and safely reroute and alter speed of the vessel to maintain appropriate operational distance and determines applicable COLREG responses. The system can track multiple obstacles simultaneously with configurable tracking guard range. (Sea machines, 2022). Katana vessel system´s technical details and payload are presented in the following table.

Platform	**Systems and capabilities**
Total Length 11.90 m	Navigation equipment, including radar and AIS.
Total Width 2.81 m	Electro-optical day and night or thermal cameras.
Weight 6,500 Kg	Laser Designator, Range Finder and Laser Pointer.
Top Speed 60 knots	Communication LOS and NLOS radio channels.
Cruising Speed 30 knots	Payload Weight 2,200 Kg.
Maritime Diesel Engines 2 x 560 Hp	Mission Endurance 350 nm.

Table 4: Katana system technical information (Israel Aerospace Industries, 2021).

ATLAS ELEKTRONIK UK´s Remote Combined Influence Minesweeping System (ARCIMS) is an unmanned naval system that is designed for the detection and classification of mines, submarines and surface platforms. The system consist of integration of sensor packages into a platform allowing fully autonomous, remote-controlled or manned operations. The ARCIMS is in operational use in number of navies including the Royal Navy. The platform is certified by the United Kingdom Maritime and Coastguard Agency (MCA) in accordance with the Code of Practice for the Safety of Small commercial Motor Vessels. The ARCIMS is fitted with COLREG compliant lights and shapes for towing and minesweeping operations as well as SOLAS compliant lifesaving equipment for manned operation. (AEUK, 2021).

ARCIMS vessel system contains a Sea-class marine craft. Main Features of the Sea-class 11 craft include an autonomy engine compatibility. The sense and avoid system can automatically detect obstacles, assess the situation and conduct avoidance manoeuvres to avoid obstacles. The system provides situation awareness to the remote operators who maintain proper look out in accordance with COLREGs. (AEUK, 2021). ARCIMS vessel system´s technical vessel details are presented in table 5.

Platform	**Systems and capabilities**
Total Length 11.0 m	Navigation equipment, including radar and AIS.
Maximum beam 3.35 m	Electro-optical day and night or thermal cameras.
Displacement (light ship) 9,500 kg	Audio sensing capability.
Draft (full load) 0.775m	Sense and avoid system.
Propulsion Twin engine, Water-jet	Control with automatic, remote and manual modes.
Speed up to 40 knots	Mission module for mine sweeping, mine hunting, hydrographic operations, ASW, maritime security and force protection.
Operation MCA 60 Miles, Category 2	Payload Capacity 4,000 kg.

Table 5: ARCIMS system technical information (AEUK, 2021).

ARCIMS´ Command, Control and Communications (C3) can be operated from a ship or a shore-side control system. The system is typically operated by two operators. The shipborne C3 can be fully integrated with the ship's combat (or operation) management system or it can be installed on-board a ship as a stand-alone system. The C3 is also available as a shore-side portable system, which has been supplied as a containerised solution, enabling remote operations from a port. A hand held console may be supplied as a second means of remote-controlled operations especially for controlling the USV at short range during deployment and recovery operations. The operation modes include a manual, a remote-control and an autonomous mode. In manual mode the vessel is steered by a helmsman on-board the boat, using either the wheel and throttle or the mouse-bot control for close quarters manoeuvring. In remote-control mode, the operators use a control console for the remote-control. The operators set a heading and speed and the vessel follows it. In the autonomous mode the system will be in control of the navigation using sense and avoid system. (AEUK, 2021).

6.4 Summary

Chapter 6 describes a system that contributes to remote USV operations in the context of this thesis and answers the second research question, “What are the remote operated systems?” An operation management system is described only to the level that is sufficient for the remote operations and an analysis of system requirements is designed to keep the classification level of the thesis unclassified. The navigation system description includes a general composition of navigation systems and examples of an integrated bridge system and an unmanned vessel´s navigation systems. The unmanned surface vessel systems include definitions and general description of the systems on-board an USV. Two examples of USVs with general capability descriptions are presented to complete the remote operated systems. All operated systems are also presented from technical perspective to support analysis of the system design requirements.

7 The Goal-Directed Task Analysis of the remote operators´ navigation tasks

The third research question, “What are the remote-control system operators´ goals and information, decision-making and situation awareness requirements in navigation tasks?” is answered in Chapter 7. Additionally, the content of the Chapter 7 contributes to answering the fourth research question, “What are system requirements for a remote-control system?” by including the goal structure of the remote operators´ navigation tasks and summary of results of the GDTA. In the GDTA, the remote operator’s navigation tasks are presented as the operators´ overall goal and it´s sub-goals.

The Goal-Directed Task Analysis of the remote operators´ navigation tasks was conducted with five subject matter experts in five analysis workshops. The literature review was used to establish the operators´ preliminary goals. Interviews were used to complement the preliminary analysis work and as baseline material for the following workshops. Semi-structured interview questions and workshop topics are presented in Appendix 3. Brainstorming, discussion, deductions and conclusions were used as working methods within the team of subject matter experts. The interviewees selected for the GDTA are subject matter experts who have extensive knowledge of the operators’ tasks. They are experts on navigation or navigation systems as well as the vessel and operation management system designers and suppliers. The team of subject matter experts have altogether more than 30 years of experience of navigating military vessels and small boats operations and more than 60 years of experience of design, development and delivery of navigation and operation management systems.

The GDTA utilised literature sources, interviews, workshops and design conducted in ongoing research and development project in the ATLAS ELEKTRONIK group concerning remotely operated vessel. Even though none of the subject matter experts have practical experience of the remote-control of the vessel, the overall experience of the team may be considered adequate to analyse the remote operators´ navigation tasks. Preliminary operators´ goal structure was established in the first analysis workshop with three of the subject matter experts. The operator’s goals were established based on navigation functions, tasks of navigation, Bridge Procedure Guide, Navigation in Coastal Waters, best practices of EDA (2018), remote operated system descriptions and using the GDTA for airline pilots (Endsley & Jones, 2011, p. 297-338) as references.

After the first workshop, the interview questions were provided to subject matter experts before the interviews to support the establishment of the operators´ goals, information the operators need to achieve their goals, required decisions and system requirements. These questions were used as a structure to discuss and further analyse the operators´ goals, information, decisions and levels of SA as well as the system requirements. The interviews were not recorded to keep the discussion as practical and relaxed as possible; however, extensive notes were taken during each session and the notes were organised based on their topics. Notes were compiled after the interviews. The operators´ goal structure was updated and initial versions of the operators´ information requirements as well as checks, choices and decisions were established by the author of the thesis.

The second analysis workshop was conducted together with the subject matter experts. In the workshop, updated operators´ goal structure and established initial versions of information and decisions were reviewed. The content of interview questions regarding navigation functions, tasks and goals provided an agenda for workshops. The operators´ goal structure was further analysed and updated during the workshop. The initial sets of required information and required decisions were enhanced and streamlined. As conclusion of the second workshop, updated versions of the operators´ goal structure and information the operators need to achieve their goals and required decisions were established. The operators´ goal structure, information requirements and the operators´ checks, choices and decisions were refined and updated by the author of the thesis after the second workshop based on the notes and conclusions of the workshop.

The third analysis workshop was arranged in a similar way than the second workshop. In the workshop, the operators´ goal structure, information the operators need to achieve their goals and required decisions were reviewed and updated. The levels of SA related to the decisions were included in the decisions. The operators´ goal structure, information requirements and the operators´ checks, choices and decisions with levels of SA were refined and updated by the author of the thesis after the third workshop based on the notes and conclusions of the workshop.

During the fourth workshop, the operators´ goal structure, information requirements, the operators´ checks, choices or decisions and levels of SA were reviewed, streamlined and updated again. The first draft set of system requirements based on interviews was reviewed in the fourth workshop and a set of system requirements was established. The system requirements were derived from the operators´ goal structure, information requirements and the operators´ checks, choices and decisions. The operators´ goal structure, information requirements and decisions with levels of SA as well as the system requirements were refined and updated by the author of the thesis after the fourth workshop based on the notes and conclusions of the workshop.

In the fifth workshop the final versions of the operators´ goals, information requirements, checks, choices and decisions with levels of SA and the system requirements were defined. The analysis process to establish Goal-Directed Task Analysis of the remote operators´ navigation tasks was relatively long lasting. The analysis process took more than a year from the beginning to the final stage, mainly because of the Covid situation and the availability of the subject matter experts. The goals were reviewed, iterated, refined, fine-tuned and updated more than ten times during workshops together with the team of SME´s and between them by the author of the thesis. The operators´ checks, choices and decisions with levels of SA as well as the system requirements were reviewed, iterated, refined and updated on a similar manner as the goals several times during the analysis work.

7.1 Framework scenario

The operational framework scenario established for the analysis includes sea surveillance tasks of an Offshore Patrol Vessel (OPV) in a limited sea area (e.g. the Gulf of Finland). The OPV may use a remote-controlled unmanned surface vessel for intelligence, surveillance and reconnaissance supporting the establishment of maritime situation picture. Surveillance systems on-board the USV include radars, electro-optical surveillance and reconnaissance equipment. All systems are remotely operated from the mother ship. The mother ship´s operation management system gathers, combines and presents situation awareness data that is transferred from sensors and equipment on-board the USV. The operation management system includes a control system for remote monitoring and controlling the USV and its systems. In the context of this thesis, remote-controlled operations are limited to remote navigation and establishing recognized maritime picture using a remote-controlled USV. The environmental operating area for the USV is littoral sea area and archipelago with confided fairways, shallow waters and multiple obstacles.

The remote operators´ mission is to use the USV for supporting maritime surveillance in the archipelago and navigate along the fairways and narrow channels towards the open sea area. The visibility is currently fair, the wind speed is 8 m/s and the temperature is +10º C. The scenario includes day, night and poor visibility conditions. Along the fairways, there are narrow channels and navigational safety devices such as navigation buoys, lanterns and beacons as well as crossing traffic where the USV is both a giveaway and a stand-on vessel. Estimated major navigational risks defined for the use case include collision with other vessels because of weather conditions, reduced visibility or failure in compliancy with COLREGs and collision or contact with pleasure crafts, foreign objects or obstacles (non-detected and detected). Additionally, the navigational risks include collision with static objects (navigation buoys, lanterns or beacons) due to weather conditions or reduced visibility and grounding because of loss of propulsion, loss of steering control or deviation from planned route.

A generic USV used in this context is defined as a vessel with features presented in table 6. The degree of autonomy of the USV is determined using definitions presented in Chapter 2. The generic USV is a category three vessel, which means that the ship is controlled and operated from another location and there are no seafarers on-board. A system composition on-board an USV consist of a navigation equipment, including navigation radar and AIS, LIDAR or other close proximity sensor, electro-optical day and night or thermal cameras, audio sensing capability, voice communication system, sense and avoid system, control system with automatic, remote-controlled and manual modes. Payload systems may vary according to mission and tasks of the USV including ISR sensors and systems, firefighting capabilities, acoustic hailing systems, electronic warfare systems, mine hunting and sweeping systems as well as sonars and weapon systems.

Platform	**Systems and capabilities**
Length 11.0 m	Navigation equipment, including navigation radar, ECDIS and AIS, heading and bearing repeater system, electromagnetic speed log, depth sounder, GNSS, meteorological system, magnetic and gyro compass system, navigation lights, search lights, signal lights and voyage data recorder.
Beam 3.0 m	Electro-optical surveillance system including day light and thermal cameras for outside surveillance with pan-tilt-zoom and 360 degrees panoramic view capability and on-board camera system for indoors monitoring inside the vessel cockpit and engine room.
Displacement (light ship) 7500 kg	Laser Range Finder.
Speed +30 knots	Communication system with line of sight and non-line of sight radio links.
Maritime Diesel Engines 2 x 500 Hp	Audio sensing capability.
Propulsion Twin engine, water-jets	Engine and propulsion system controls.
Payload capacity +2000 Kg	Integrated automation system for platform management (control and monitoring of engine, propulsion, power management and auxiliary systems).
Mission Endurance +200 nm	On-board computer system to enable remote control of the vessel.
Other	Payload for intelligence, surveillance, reconnaissance and support for search and rescue.
Other	Sense and avoid system to support remote operators´ situation awareness.

Table 6: A generic USV used in the context of this thesis.

7.2 The remote operators´ overall goal

The remote-control system operators´ task of is to monitor and control the unmanned surface vessel operations. This task includes many sub-tasks and their sub-tasks and seems to be rather complicated. Successful conducting of the tasks require efficient means for monitoring the USV´s systems and statuses of them, position and behaviour of the vessel as well as the environment and events outside the vessel. How the remote-control system operators succeed in monitoring tasks does not only depend on how good quality of data the sensors on-board the USV can provide, but also how good level of situation awareness the operation management system can provide for the remote operators.

The operators´ overall goal in this analysis is defined as, *"Steer the USV remotely from origin to destination and back safely, legally and efficiently"*. The overall goal reflects in this case the overarching objective of the remote-control system´s mission. Legal in this context is understood as following the laws, rules and regulations. In practise the objective is to drive the USV remotely from harbour or mother ship to the mission area, complete all tasks set to the vessel´s payload, accomplish the mission and drive the USV back to the origin or other pre-defined destination safely and securely, according to rules and regulations and as efficient as feasible. The GDTA analysis include altogether one overall goal, four sub-level one goals, 20 sub-level two goals, 89 sub-level three and 20 sub-level four goals.

7.3 Sub-level goals

The overall operators´ goal includes four sub-level one goals as follows:

1. *A safe and efficient passage plan to destination and back is established*
2. *The pre-departure procedures are completed*
3. *The passage is executed safely, legally and efficiently*
4. *The post-mission analysis is conducted, documented and briefed.*

To keep the analysis simple and understandable the overall goal is divided into sub-level one goals that include passage planning, pre-departure procedures, execution of the passage and post-mission analysis. The first two sub-level one goals describe planning and preparations for the mission. The third sub-level one goal may be seen as the most the decisive goal, since the execution of the navigation tasks is included in that goal. The first sub-level two goal of the execution of passage is defined as, "Vessel is operated safely, legally and efficiently" that is an overarching goal for the whole vessel operations and execution of the passage. Other sub-level two goals include cast off, close quarters manoeuvring, fairway navigation in the archipelago, open sea navigation and mooring procedures. These sub-level goals have several similar sub-goals since the navigation tasks include similar parts in each one of them. Sub-goals such as the passage plan is valid, all systems are working without major errors, a proper lookout is executed, the vessel is in safe position etc. are similar to all sub-level two goals that relate to execution of cast off, manoeuvring, fairway and open sea navigation as well as mooring. Therefore, there are repetition in the goal hierarchy and results of the GDTA.

Some of the sub-level goals and results may be exactly same for example in fairway and open sea navigation; however, the scale of operations, the distance and time to face risks and hazards and the time window to make correct decisions and execute manoeuvres safely may be different within achievement of these goals. The time window for decision-making in the archipelago can be considerably smaller than at the open sea. The difference between the two operating areas is likely because of higher number of targets, risk factors and hazards, blind spots of observation and narrow time and space in the archipelago as well as the operators´ ability to comprehend the current situation and project the future status in rapid situations. Additionally, possible control delays affect safe operations, especially in the archipelago. Although, for example sub-goals 3.4 and 3.5 appear to be technically similar, the environmental and risk factors as well as the time for correct decision-making and control activities may differ significantly from the operators´ point of view.

The fourth sub-level one goal consists of post-mission analysis, recording and de-briefing the tasks and the mission after they have been conducted and accomplished. Post-mission analysis is decided to be included in the GDTA even though it may not be actually a goal for the operators. It is seen as a crucial part of the process where the safety, legitimacy and efficiency are to be analysed, documented and briefed to the remote-control team. All sub-level one goals are divided into several sub-level goals that the operators need to achieve in order to achieve the upper level goal.

7.3.1 A safe and efficient passage plan is established

The first sub-level one goal, “A safe and efficient passage plan to destination and back is established” is divided into five sub-level two goals. Sub-level two goals are as follows:

- 1.1 Appraisal process is completed, all relevant information is collected, assessed, perceived and comprehended
- 1.2 Passage plan is defined, assessed, comprehended and selected
- 1.3 Cast off, mooring, manoeuvring, navigation, contingency and emergency plans are defined.
- 1.4 Plans to conduct payload mission and tasks are completed
- 1.5 Plan is approved and briefed to the remote-control team.

Sub-level two goal 1.1, “Appraisal process is completed, all relevant information is collected, assessed, perceived and comprehended” is analysed to have five sub-level three goals.

- 1.1.1 General and operational factors are known, assessed and comprehended
- 1.1.2 Navigational factors are known, assessed and comprehended
- 1.1.3 Weather conditions and other environmental factors are known, assessed and comprehended
- 1.1.4 Contingency and emergency factors are defined, assessed and comprehended
- 1.1.5 All other relevant risk factors are known, assessed, comprehended, managed and mitigated.

Sub-level two goal 1.2, “Passage plan is defined, assessed, comprehended and selected“ includes seven sub-level three goals.

- 1.2.1 Safe and efficient routes are assessed, planning tools (e.g. ECDIS) are used to define safe and efficient route
- 1.2.2 Weather, visibility, traffic, mission, archipelago, fairways and sea area effects to the plan are assessed and defined
- 1.2.3 Risks and hazardous areas are assessed and defined
- 1.2.4 All relevant risks and hazards are assessed and effects to the plan are defined
- 1.2.5 Waypoints, safe speed and course assessed and defined
- 1.2.6 The route is re-evaluated and re-planned (when required)
- 1.2.7 The best and safe route is selected, comprehended and briefed to the remote-control team.

Sub-level two goal 1.3, “Cast off, mooring, manoeuvring, navigation, contingency and emergency plans are defined” contains five sub-level three goals.

- 1.3.1 Cast off and mooring plans considering conditions, traffic, visibility and weather conditions are defined
- 1.3.2 Manoeuvring and navigation plans are defined
- 1.3.3 Contingency plans and routes are defined
- 1.3.4 Contingency routes to anticipate changes in risks, mission (and payload), weather or other conditions or anomalies are defined

  - 1.3.5 Emergency plans are defined.

Sub-level two goal 1.4, “Plans to conduct payload mission and tasks are completed” is essential for payload mission planning; however, the payload system is outside of the scope of this thesis and may be analysed during the mission system payload detailed design.

Sub-level two goal 1.5, “Plan is approved and briefed to the remote-control team” comprises three sub-level three goals.

- 1.5.1 Planning is completed
- 1.5.2 The plan is approved by the Master
- 1.5.3 The plan is briefed to the remote-control team.

7.3.2 Pre-departure procedures are completed

The second sub-level one goal, “Pre-departure procedures are completed” is divided into six sub-level two goals. Sub-level two goals are as follows:

- 2.1 Weather conditions, operation area and risk factors are assessed and comprehended
- 2.2 All vessel systems are tested, checked and ready for use
- 2.3 Vessel´s seaworthiness is checked and the vessel is ready for going to the sea
- 2.4 Remote-control system is properly manned and crew is on-board (if required for cast off or mooring procedures)
- 2.5 All remote-control systems are tested, checked and ready for use
- 2.6 Payload systems are tested, checked and ready for use.

Sub-level two goal 2.1, “Weather conditions and other environmental factors are assessed and comprehended” is analysed to have six sub-level three goals.

- 2.1.1 Weather forecasts are received, assessed and comprehended
- 2.1.2 Visibility conditions are assessed and comprehended
- 2.1.3 Traffic situation underway is assessed and comprehended
- 2.1.4 Operation area is assessed and comprehended
- 2.1.5 All environmental conditions and foreseen changes are assessed and comprehended
- 2.1.6 All hazardous areas and other risk factors are assessed and comprehended.

Sub-level two goal 2.2, “All vessel systems are tested, checked and ready for use” includes three sub-level three goals.

- 2.2.1 All systems are started, prepared and configured for the mission
    - Navigation system
    - Engines and propulsion system
    - Engine and propulsion control system
    - Power distribution system
    - Sensor system, e.g. radars (lidar) and cameras
    - Communication system
    - Payload system and cargo (if any)
    - Other systems e.g. remote-control computer or sense and avoid system
- 2.2.2 System tests and checks are documented to predefined checklists and recorded
- 2.2.3 System tests and checks are completed, no major alerts are existing, status of systems are comprehended and all systems are ready for use.

Sub-level two goal 2.3, “Vessel´s seaworthiness is checked and the vessel is ready for going to the sea” contains four sub-level three goals.

- 2.3.1 Hull and superstructure openings and watertight doors are closed
- 2.3.2 Stability and draft information is available and comprehended
- 2.3.3 Payload and cargo (if any) is safely secured
- 2.3.4 Vessel is prepared and ready for cast off.

Sub-level two goal 2.4, “Remote-control system is properly manned and crew is on-board (if required for cast off or mooring procedures)” has six sub-level three goals.

- 2.4.1 Master, navigator, lookout, operators and other required manning is ready in remote-control system
- 2.4.2 All procedures and checklists for safe operations are completed and approved
- 2.4.3 Personnel is adequately trained and experienced for duties
- 2.4.4 Duties are clear, allocated and rehearsed
- 2.4.5 Possible change of watches are planned and rehearsed
- 2.4.6 Adequate crew is on-board (if required for cast off).

Sub-level two goal 2.5, “All remote-control system are tested, checked and ready for use” comprises three sub-level three goals.

- 2.5.1 Systems are started, prepared and configured for the mission
- 2.5.2 System tests and checks are documented to predefined checklists and recorded
- 2.5.3 System tests and checks are completed, no major alerts are existing, status of systems are comprehended and all systems are ready for use.

Sub-level two goal 2.6, “Payload systems are tested, checked and ready for use” embodies three sub-level three goals similar to 2.2 and 2.5.

- 2.6.1 Systems are started, prepared and configured for the mission
- 2.6.2 System tests and checks are documented to predefined checklists and recorded
- 2.6.2 System tests and checks are completed, no major alerts are existing, status of systems are comprehended and all systems are ready for use.

7.3.3 Passage is executed safely, legally and efficiently

The third sub-level one goal, “Passage is executed safely, legally and efficiently” is divided into six sub-level two goals. Sub-level two goals are as follows:

- 3.1 Vessel is operated safely, legally and efficiently.
- 3.2 Cast off procedures are executed safely, legally and efficiently
- 3.3 Close quarters manoeuvring is executed safely, legally and efficiently
- 3.4 Fairway navigation is executed safely, legally and efficiently
- 3.5 Open sea navigation is executed safely, legally and efficiently
- 3.6 Mooring procedures are executed safely, legally and efficiently.

Sub-level two goals include several sub-level three goals that are similar for two or more sub-level goals. These sub-level goals are marked with *. Sub-level two goal 3.1, “Vessel is operated safely, legally and efficiently” embodies six sub-level three goals.

- 3.1.1 All systems in USV, RCS and payload are functioning properly without major errors or alerts. This goal contains two sub-level 4 goals
    - 3.1.1.1 Systems conduct healthy checks and provide alarms when required
    - 3.1.1.2 Systems are redundant and resilient.

- 3.1.2 USV systems provide high quality data to enable safe and secure remote monitoring and control. This goal contains two sub-level 4 goals
    - 3.1.2.1 Engines, power supply, propulsion, steering, navigation, surveillance, situation awareness, grounding, collision avoidance, communication, payload and other systems gather and distribute high quality of data
    - 3.1.2.2 Received data from USV is secured and reliable with high level of data quality, accuracy and integrity with minimal errors and delays.
- 3.1.3 The operators have sufficient situation awareness for safe and efficient remote operations. This goal contains three sub-level 4 goals
    - 3.1.3.1 The operators perceive all elements and risks in the environment, comprehend the current situation and project the future status adequately
    - 3.1.3.2 The operators share situation awareness and communicate efficiently
    - 3.1.3.3 The operator team makes correct and timely accurate decisions based on adequate situation awareness and risk assessment
- 3.1.4 All USV, RCS and payload systems are continuously under efficient and reliable monitoring and control. This goal contains five sub-level 4 goals
    - 3.1.4.1 All systems are continuously monitored and controlled efficiently
    - 3.1.4.2 The operators monitor all systems efficiently and the operators are in the loop during the operation
    - 3.1.4.3 The operators control all systems efficiently with minimal errors and delays
    - 3.1.4.4 Efficient remote fire and damage control is enabled
    - 3.1.4.5 Efficient remote emergency and fail-safe procedures including anchoring, dynamic positioning, other safety modes or safe return to port are enabled.
- 3.1.5 Vessel is in safe position related to other vessels and hazards and acting according to COLREGS. This goal contains three sub-level 4 goals.
    - 3.1.5.1 Vessel´s position, course and speed are accurate, secured, safe and comprehended correctly
    - 3.1.5.2 Position and kinetics of other vessels or hazards are accurate, secured, safe and comprehended correctly
    - 3.1.5.3 USV systems and the operators are aware of vessel´s position and situation related to COLREGs and are able to act accordingly.

- 3.1.6 The operators´ team resources are managed effectively and efficiently. This goal contains five sub-level 4 goals.
    - 3.1.6.1 Operations and systems are optimized according to team´s competency and reliability
    - 3.1.6.2 Operations and systems are optimized according to status and reliability of vessel systems, weather and other conditions
    - 3.1.6.3 The operator team communicates and is informed at sufficient level
    - 3.1.6.4 Risks and effects to operations are minimised
    - 3.1.6.5 System´s and the operators´ abnormalities are minimised.

Sub-level two goal 3.2: “Cast off procedures are executed safely, legally and efficiently” is analysed to have eight sub-level three goals.

- 3.2.1 Passage plan is valid *
- 3.2.2 All USV, RCS and payload systems are functioning without major errors and alerts *
- 3.2.3 Proper lookout, voice and data communication are executed, reporting to port authorities or VTS is executed (if required) *
- 3.2.4 Vessel´s position, course and speed are secured, safe and comprehended *
- 3.2.5 Position and kinetics of other vessels or hazards are known and comprehended *
- 3.2.6 Vessel is in safe position and manoeuvers according to COLREGs *
- 3.2.7 All ropes, equipment and decks are cleared
- 3.2.8 Cast off is completed safely and vessel is ready for close quarter’s manoeuvres.

Sub-level two goal 3.3: “Close quarters manoeuvring is executed safely, legally and efficiently” includes eight sub-level three goals.

- The first six sub-level three goals 3.3.1 - 3.3.6 are general vessel operation goals similar to 3.2.1-3.2.6 presented in the previous goal *
- 3.2.7 Vessel is manoeuvred to clear and safe distance form pier or mother ship
- 3.2.8 Close quarters manoeuvring is completed safely and vessel is ready for fairway navigation.

Sub-level two goal 3.4: “Fairway navigation is executed safely, legally and efficiently” contains seven sub-level three goals.

- The first six sub-level three goals 3.4.1-3.4.6 are general vessel operation goals similar to 3.2.1-3.2.6 and 3.3.1-3.3.6 *
- 3.4.7 Fairway navigation is completed safely and vessel is ready for open sea navigation if required or close quarters or mooring manoeuvres.

Sub-level two goal 3.5: “Open sea navigation is executed safely, legally and efficiently” has seven sub-level three goals.

- The first six sub-level three goals 3.5.1-3.5.6 are general vessel operation goals similar to 3.2.1-3.2.6, 3.3.1-3.3.6 and 3.4.1-3.4.6 *
- 3.5.7 Open sea navigation is completed safely and vessel is ready for fairway navigation or close quarters or mooring manoeuvres.

Sub-level two goal 3.6: “Mooring procedures are executed safely, legally and efficiently” comprises eight sub-level three goals.

- 3.6.1 Mooring plan and procedures are valid and USV is ready for mooring
- The following five sub-level three goals 3.6.2-3.6.6 are general vessel operation goals similar to 3.1.2-3.1.6, 3.2.2-3.2.6, 3.3.2-3.3.6, 3.4.2-3.4.6 and 3.5.2-3.5.6 *
- 3.6.7 Ropes, equipment and decks are cleared and mooring is completed
- 3.6.8 Vessel is secured alongside a pier or mother ship and systems are shut down on controlled manner.

The third sub-level one goal “Passage is executed safely, legally and efficiently” together with six sub-level two goals, 44 sub-level three goals and 20 sub-level four goals contains the essence of remote navigation because the goals include conducting the voyage in practice and operating all systems on-board the USV and at the remote-control system. These goals have a number of common sub-goals and therefore include several similar information requirements, the operators´ checks, choices or decisions as well as requirements for the remote-control system.

7.3.4 Post-mission analysis is conducted, documented and briefed

The fourth sub-level one goal: “Post-mission analysis is conducted, documented and briefed” is divided into three sub-level two goals that all relate to the situation when the operators want to conduct post-mission activities and further develop their operations. Sub-level two goals are as follows:

- 4.1 Post-mission analysis is conducted adequately
- 4.2 Post-mission analysis is documented properly
- 4.3 Post-mission analysis is briefed to the remote-control team.

The fourth sub-level one goal and sub-level two goals are not analysed any further, since they are considered to be outside the core scope of this thesis. The post-mission analysis and briefing tools can be included in the operation management system software when sufficient voyage and operation data recording capabilities are included.

7.4 Results of the Goal-Directed Task Analysis

Results of the GDTA include information the operators need to accomplish the tasks and achieve their goals, operators´ checks, choices and decisions as well as requirements for the remote-control system. References to goals are shown in brackets. Situation awareness levels shown for every required check, choice and decision are based on Endsley´s categories. They are presented to show which level of SA the operators need and how the system must support the operators to conduct their tasks. Some of the goals, especially sub-level goal 3, “Passage is executed safely, legally and efficiently” have the same or similar sub-level goals and therefore share similar requirements. The results of the analysis contain repetition because the goals are almost or exactly the same in several different sub-goals.

Cognitive decision-making points when the operators may have to combine information from various sources and make cognitive deductions and decisions are in *Italics*. For example, the decision of how much it is required to control speed and course to port or starboard requires cognitive decisions based on perception of the elements in the environment, comprehension of the current situation and projection of the future status. Decisions regarding is the vessel in safe position related to other vessels and hazards, is the vessel acting according to COLREGS currently and the near future, is it required to take over control from automatic navigation system, is it safe to proceed and what will happen next and in the near future are cross cutting through all goals and therefore regarded as the most important individual decisions that the operators have to make. Requirements for the remote-control system are analysed and derived from the information the operators need and checks, choices and decisions the operators need to make to achieve the goal. Requirements, decisions and information are interlinked and should be examined together to make their connection clear. Detailed results of the GDTA are presented in Appendices 1 and 2.

8 Conclusions, discussion and critical review

The first Chapters of the thesis contain the framework and theoretical part that was reviewed using literature sources, standards and guidelines. The aim was to use only valid sources that concern the scope of the thesis and examine those parts that provide added value to the context of the study. Standards related to unmanned operations are limited even though they contain plenty of information relevant to this study. Classification publications and the best practises include hundreds of guidelines. All of them are not within the scope of this work; however, the relevant ones are utilised in this thesis. Indications and statements provided in the sources are carefully selected; however, not all of them are actual requirements. In the field of this study the guidelines and principles are not separated and should be considered as minimum as initial requirements for the system design. When the remote-control system is developed further, a more thorough system requirement review will be needed and a set of feasible system requirements shall be established in accordance with the system design process.

The conceptual framework and theoretical basis for the design of remote-controlled operations provide a starting point for analysis of the functionalities, the operators´ goals, tasks and requirements for situation awareness in the remote-control system. Levels of autonomy and control seem to vary depending on definitions by different organisations; however, they have several similarities and therefore form a feasible basis for continuing the analysis work. The definitions of autonomy and control state the level of automation and the human operator roles in remote operations. They seem to be rather valid for analysing, planning and determining tasks for a remote-control system. A human operator as a decision-maker is in the centre, one way or another, in all of the definitions regarding remote-controlled operations, including that monitoring and controlling tasks can be conducted from a mother ship or ashore. The remote sea-farers or operators perform tasks as if they were on the bridge regardless of whether there is crew on-board or somewhere else. The defined operators´ roles support analysis of remote-control system operators´ goals and tasks.

Standards and guidelines provide a framework for the design of a remote-control system and give constraints and restraints for functions, goals and tasks to be accomplished in remote operations. Ship functions presented in Chapter 4 may be combined together with the three levels of situation awareness. The first level of SA means perception and includes condition detection and interpretation. The second level of SA means comprehension, which includes condition analysis and a partial understanding of the effect of changes (action planning). The third level of SA means projection and includes action planning and action control. The quality of the operators´ SA affect performance of the ship functions and accomplishment of the tasks. This can be seen as valid in remote-control system when the operators conduct rather similar tasks with almost identical objectives and performance requirements as they were on the bridge of a manned ship. Standards, guidelines, tools and methods presented in this thesis provide a basis for further research. Task analysis tools enable possibilities to determine objectives, tasks, information, task allocation, workload and other crucial elements of the remote operators´ work.

Human factors engineering literature include methodologies to analyse, plan, evaluate and design functionalities, objectives, goals, tasks, situation awareness and design requirements. Human factors literature sources used in this thesis are quite limited and narrow even though the main sources, *Designing for People* and *Designing for Situation Awareness,* include and refer to several of research studies. Main sources are written by several distinguished authors in the field of human factors research. The limitations of used sources may affect validity and reliability of the results of the thesis.

The essential part of the thesis is the Goal-Directed Task Analysis that enabled a practical and proved method to analyse what goals must be achieved and what tasks should be conducted by the remote operators in the navigation tasks. The GDTA was established to determine what the requirements for information, decision-making and situation awareness for the remote operators are. The GDTA was analysed using literature sources of the thesis concentrating on navigation functions and tasks. The results were established in interviews, discussions and workshops with selected subject matters experts.

The conducted GDTA analysis is most certainly not exhaustive due to limited number of experts and conducted interviews, discussions and workshops. Therefore, the results should be considered as the lowest level of information that is required to achieve the analysed goals or as at least those decisions that have to be made in order to accomplish the goal, but not necessarily limited to those. For more accurate and valid information and analysis a number of further iteration rounds of interviews and workshops should be conducted. The analysed information, decisions and requirements need to be verified in a simulator test or with a prototype system in order to actually verify and validate the results. The objectiveness, reliability, validity and generalizability of the results may be questionable because of limited number of subject matter experts and conducted iteration rounds of interviews, discussions and workshops. Generalisation of the results outside the scope of this study may be not optimal without further iteration and verification measures.

The conducted GDTA supports the performance of ship functions and accomplishment of tasks related to efficient work in remote-control system. Together with standards and guidelines, the human factors engineering methods provide an empirical cognitive task analysis solution to be used in the design process. The results of the GDTA may be seen rather academic or indicate “an in the perfect world”- solution. Some of the results presented in this thesis may be only theoretical; however, they can provide answers questions such as what kind of technological HMI solutions or possibilities there should be to support the operators′ situation awareness and decision-making in the context of remote-control. Most likely only those requirements that are considered feasible or cost-effective will be selected to be used in the system design in practice. The decision regarding which requirements are actualised to practise is made by system owners, designers and other stakeholders and subject to available resources.

The GDTA results include a number of information requirements for the operators that is quite an expected result. The number of decisions, choices and checks that the operators have to make within a short time window, especially in the close proximity of shallow waters and other navigational hazards in the archipelago, are quite surprising. The results of the thesis probably gave only a tip-of-the-iceberg view regarding the requirements and practical solutions for the USV operators and the remote-control system in conditions and context of this thesis.

The concepts stating that the team of one or few operators can efficiently, safely and securely monitor and control unmanned vessel or even several vessels at the same time can be valid at open sea conditions, when operating at a rather slow speed and in light traffic conditions. The situation may be different when remotely operating the USV in very shallow and confined waters in the archipelago at a high speed and with poor visibility conditions. The team of operators may face very narrow windows for decision-making and control measures. Therefore, it may be worthwhile to validate this concept of remote-control system manning, roles, task allocation, situation awareness and workload with sufficient data from the simulations. Even though this thesis is rather theoretical and the results of the empiric part of cognitive task analysis are not fully verified or validated, I assume that this study may bring added value for system designers and certainly for future work regarding the simulator test of the remote-control system of the USV in the conditions and environment described in the thesis.

8.1 Results of the thesis

The research problem was to determine what the design requirements for remote-control system are from the user-centred perspective in the context of this thesis. Based on the information presented in Chapters 2, 3, 4 and 6, it seems that the theoretical basis and framework were analysed in a sufficient manner to give adequate background for the GDTA.

The first research question, “What is a remote-control centre?” was answered mainly in Chapter 4. Several sources, standards, guidelines and practises were reviewed and a view on what a remote-control centre is and what it is supposed to accomplish in general was described. Answers to the second research question, “What are the remote operated systems?” were given in Chapter 6. The Chapter concentrated on operation management, navigation and USV systems. Examples of systems with technical data of the systems supported the task analysis in a sufficient manner.

The third research question, “What are the remote-control system operators´ goals and information, decision-making and situation awareness requirements in navigation tasks?” was answered in Chapter 7 as well as in Appendices 1 and 2. A hierarchical GDTA analysis was conducted to determine the remote operators´ goals in navigation tasks. The GDTA resulted in altogether 134 goals for the operators to achieve. The number of goals is not the main point, the content of them is. The analysis resulted in 36 groups of information the operators need to accomplish their goals and 92 checks, choices and decisions with levels of SA that the operators work with.

Chapters 4, 5 and 7 as well as Appendix 2 contributes answering the fourth research question, “What are system requirements for a remote-control system?” Essential results of the thesis are in Appendix 2 that includes 90 requirements for the remote-control system design. These requirements are probably not the final requirements, since the requirements need further analysis and tests for verification and validation. With more iteration rounds and testing of the results, the number and content of the goals, information and decision-making requirements as well as the requirements for remote-control system design will probably change. Most likely the number regarding all of the aforementioned parts will decrease and the content of them will be clarified when results are more thoroughly analysed and combined.

8.2 Future research

Some topics for future research came up during the thesis work. The results of this thesis need to be verified and validated with a number of operators in a simulator test or with an operating prototype. The remote operator’s performance, vigilance and workload may be examined in a simulator or with a prototype as well. Additionally, remote operators´ experiences using operational systems can be studied by interviewing UAV pilots and USV navigators and utilise the interviews results to verify or validate the results of this thesis. Additionally, future research can be conducted to examine requirements for an operator team´s situation awareness, operators´ task allocation and task allocation between the human operators and the system with autonomous or adaptive automation features.

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List of tables

Tables that are presented in the thesis are in the following list.

Table 1: Levels and degrees of autonomy, associated functions and operators´ roles.

Table 2: Levels of control and control task allocation between the human operator and the system.

Table 3: The unmanned maritime system of systems.

Table 4: Katana system technical information.

Table 5: ARCIMS system technical information.

Table 6: A generic USV used in the context of this thesis.

Table 7: The results of the GDTA: Information the remote operators need to achieve their goals.

Table 8: The results of the GDTA: Checks, choices or decisions the operators need to make to achieve the goals.

Table 9: The results of the GDTA: Requirements for the remote-control system.

Table 10: Definitions and explanations.

List of figures

Figures that are illustrated in the thesis are in the following list.

Figure 1: A diagram of an NGC system for autonomous marine surface vehicles.

Figure 2: NASA´s system engineering engine.

Figure 3: An applied system development process where system requirements are defined, analysed and specified prior to system requirement review.

Figure 4: A human in the Loop.

Figure 5: Three levels of situation awareness.

Figure 6: The OODA-loop

Figure 7: The PUP-loop.

Figure 8: Generic breakdown of a ship navigation function into sub-tasks.

Figure 9: Control of a Function.

Figure 10: Remote-Control Centre supported by novel technology.

Figure 11: A simplified example of typical OMS configuration.

Figure 12: An example of devices and connections on an integrated bridge.

Figure 13: The operating principle of the USV solution.

Figure 14: Summary of the Goal-Directed Task Analysis with the operators´ overall goal, “Steer the USV remotely from origin to destination and back safely, legally and efficiently” and sub-level goals.

Figure 15: Sub-level goal 1, “A safe and efficient voyage plan to destination and back is established” with sub-level 2 and 3 goals.

Figure 16: Sub-level goal 2, “Pre-departure procedures are completed” with sub-level 2 and 3 goals.

Figure 17: Sub-level goal 3, “Passage is executed safely, legally and efficiently” with sub-level 2 and 3 goals.

Figure 18: Sub-level goal 3.1, “Vessel is operated safely, legally and efficiently” with sub-level 3 and 4 goals

Figure 19: Sub-level goal 3.2, “Cast off procedures are executed safely, legally and efficiently” with sub-level 3 goals.

Figure 20: Sub-level goal 3.3, “Close quarters manoeuvring is executed safely, legally and efficiently” with sub-level 3 goals

Figure 21: Sub-level goal 3.4, “Fairway navigation is executed safely, legally and efficiently” with sub-level 3 goals.

Figure 22: Sub-level goal 3.5, “Open sea navigation is executed safely, legally and efficiently” with sub-level 3 goals.

Figure 23: Sub-level goal 3.6, “Mooring procedures are executed safely, legally and efficiently” with sub-level 3 goals.

Figure 24: Sub-level goal 4, “Post-mission analysis is conducted, documented and briefed” with sub-level 2 goals.

Appendix 1 The Goal-Directed Task Analysis of the remote operators´ navigation tasks

Appendix 1 contributes to the third research question, “What are the remote-control system operators´ goals and information, decision-making and situation awareness requirements in navigation tasks?” by presenting the operators´ goals analysed in the GDTA.

The Goal-Directed Task Analysis of the remote operators´ navigation tasks is illustrated in this appendix in a hierarchical format. The results of the analysis are presented in Appendix 2 that should be examined together with hierarchically presented goals.

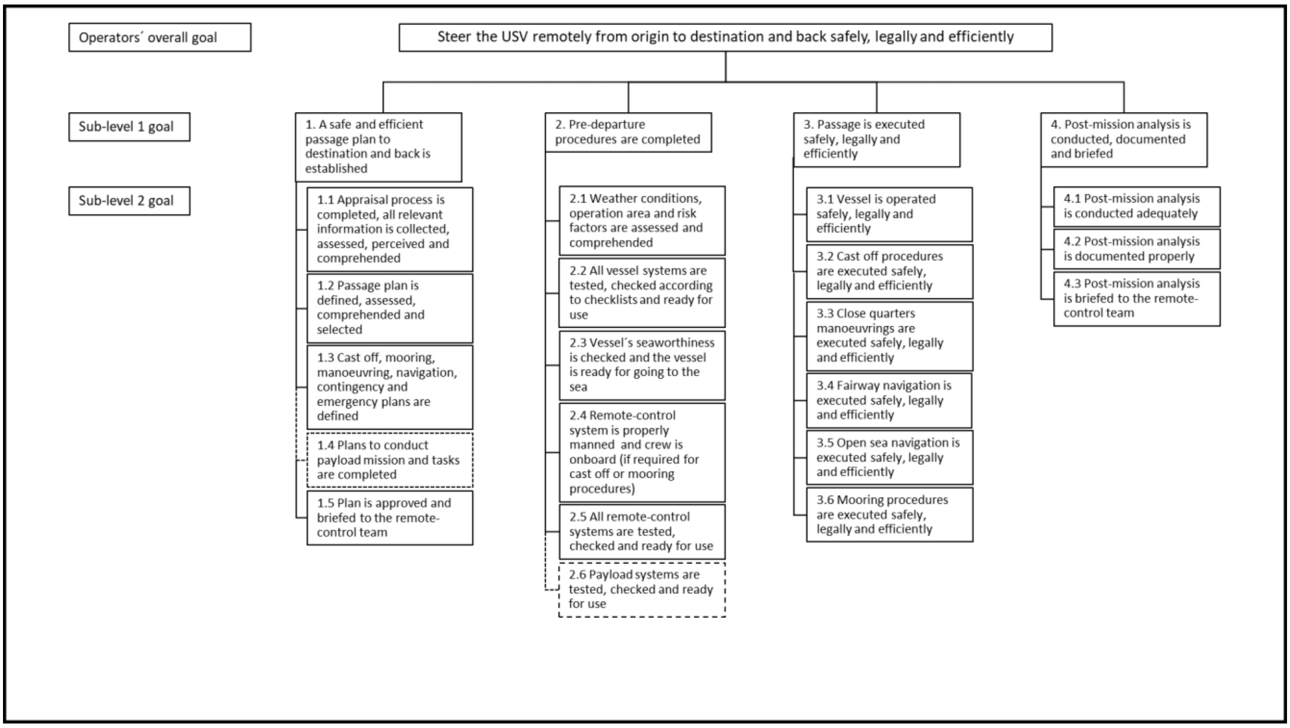

Figure 14: Summary of the Goal-Directed Task Analysis with the operators´ overall goal, “Steer the USV remotely from origin to destination and back safely, legally and efficiently” and sub-level goals.

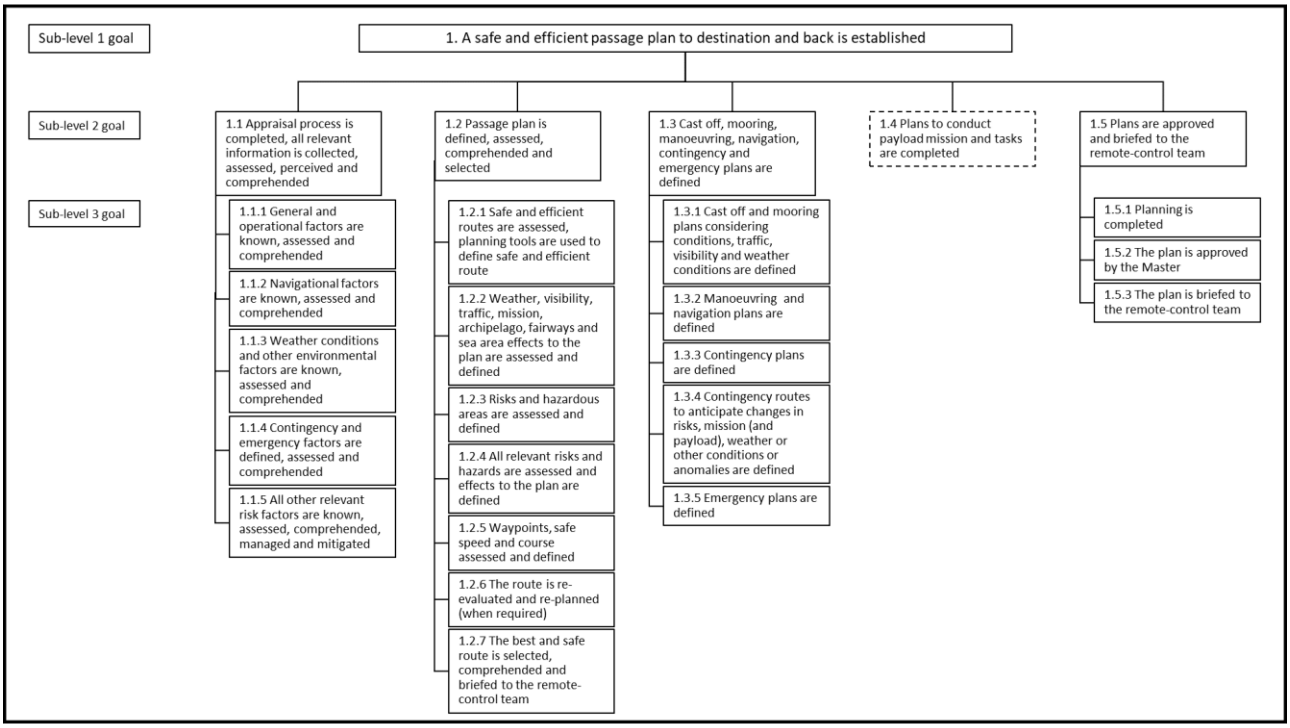

Figure 15: Sub-level goal 1, “A safe and efficient voyage plan to destination and back is established” with sub-level 2 and 3 goals.

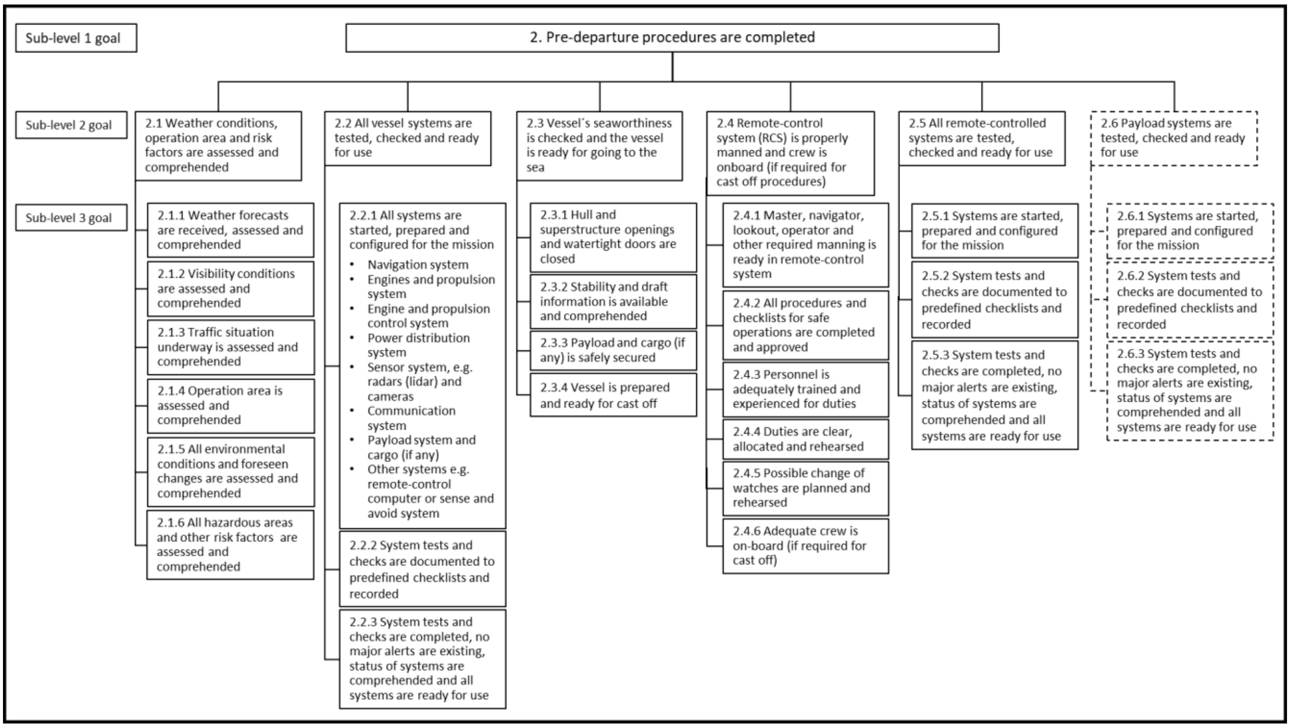

Figure 16: Sub-level goal 2, “Pre-departure procedures are completed” with sub-level 2 and 3 goals.

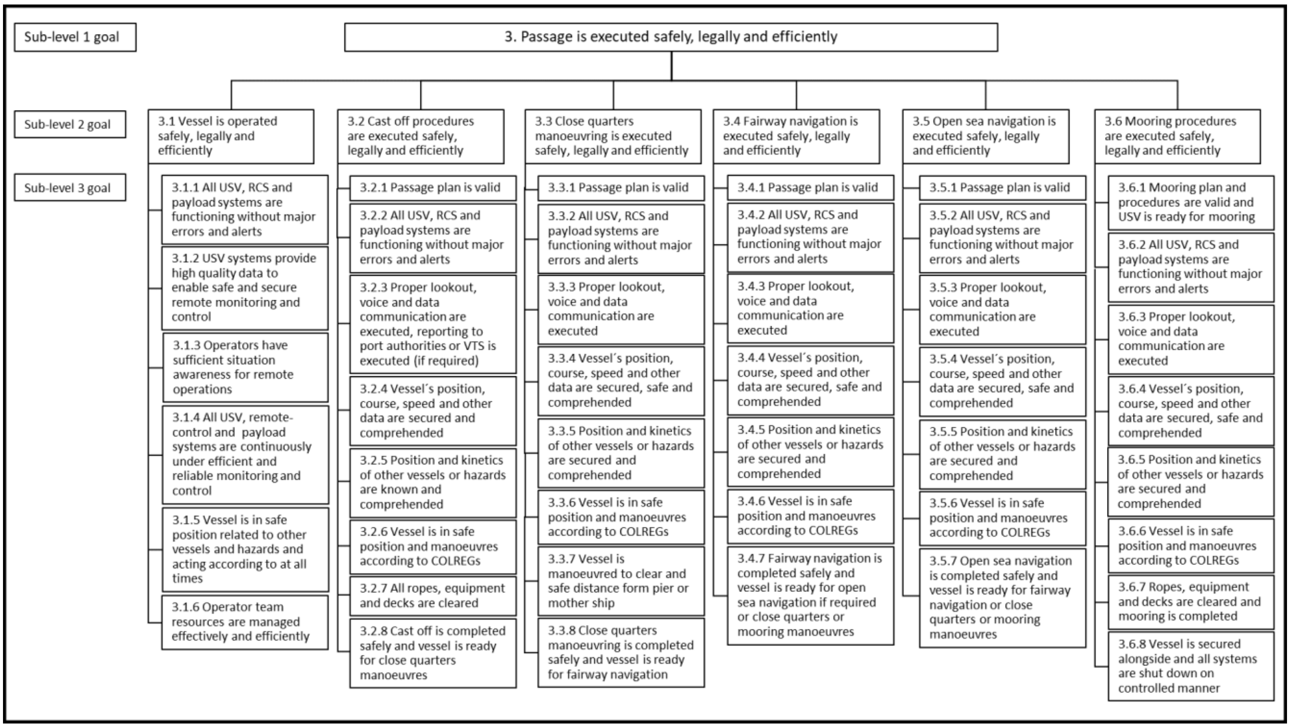

Figure 17: Sub-level goal 3, "Passage is executed safely, legally and efficiently" with sub-level 2 and 3 goals.

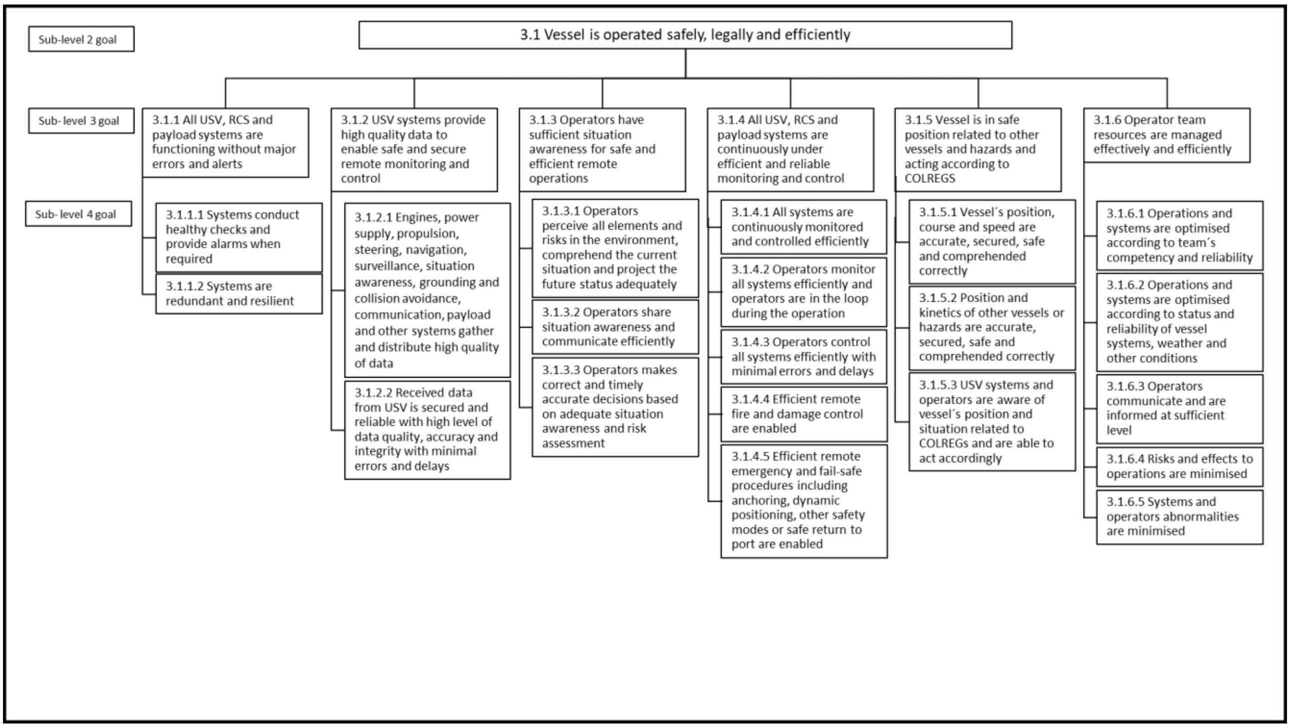

Figure 18: Sub-level goal 3.1, "Vessel is operated safely, legally and efficiently" with sub-level 3 and 4 goals.

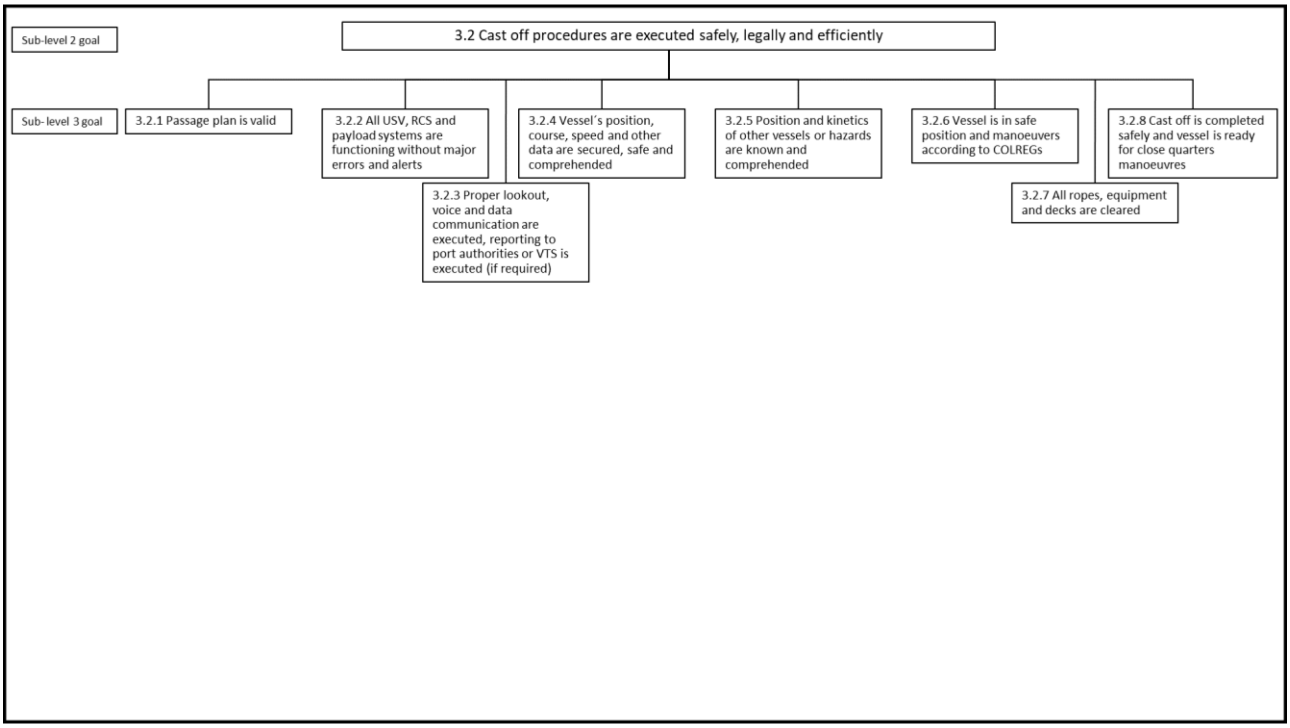

Figure 19: Sub-level goal 3.2, “Cast off procedures are executed safely, legally and efficiently” with sub-level 3 goals.

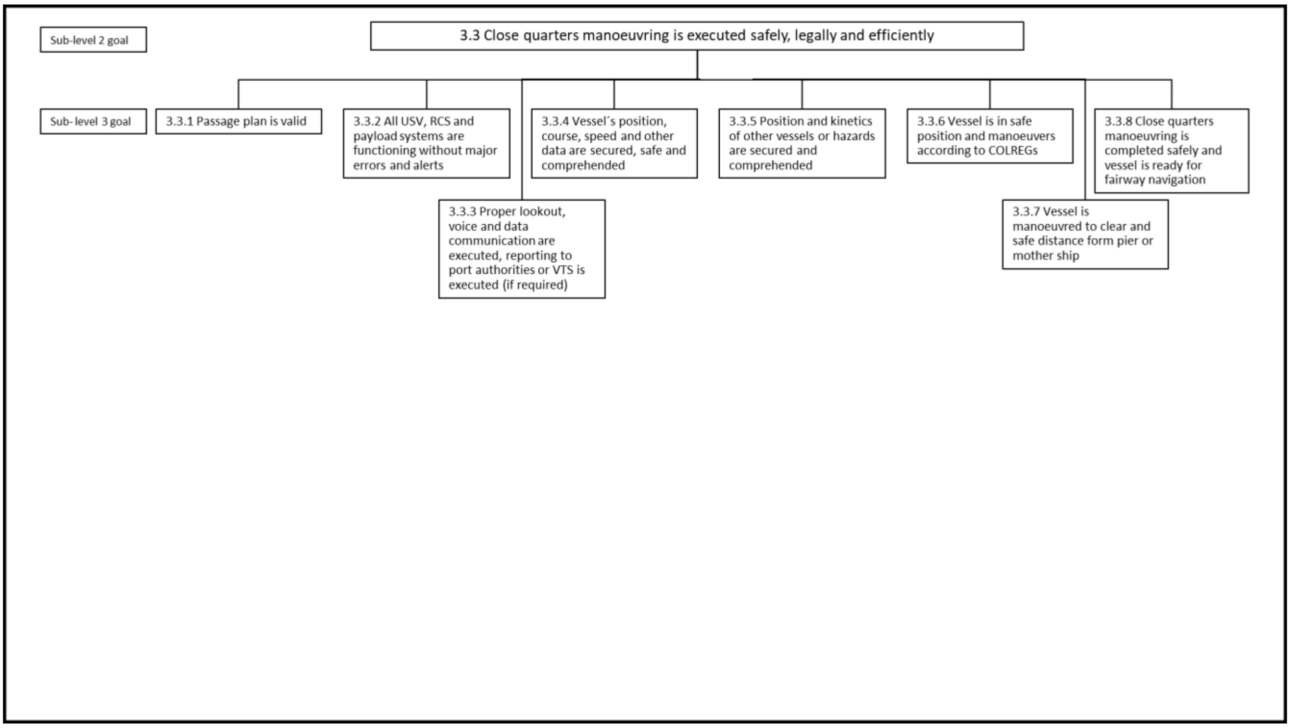

Figure 20: Sub-level goal 3.3, “Close quarters manoeuvring is executed safely, legally and efficiently” with sub-level 3 goals.

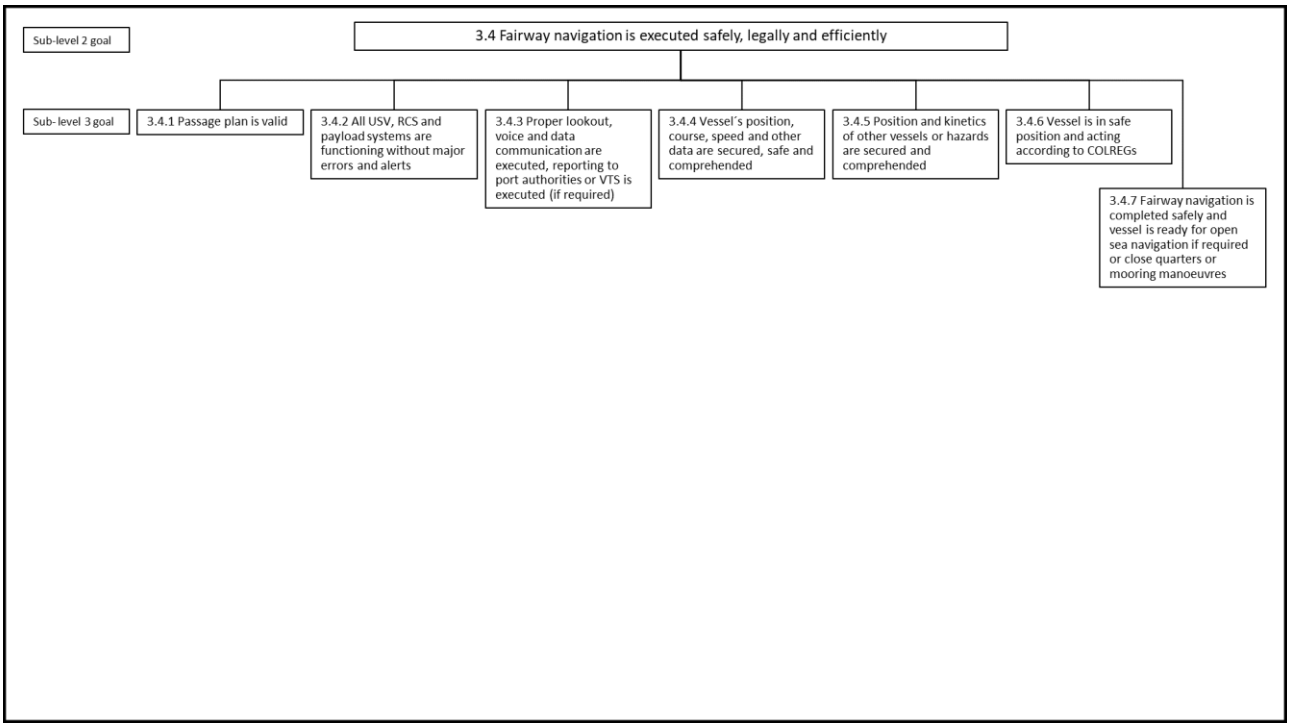

Figure 21: Sub-level goal 3.4, “Fairway navigation is executed safely, legally and efficiently” with sub-level 3 goals.

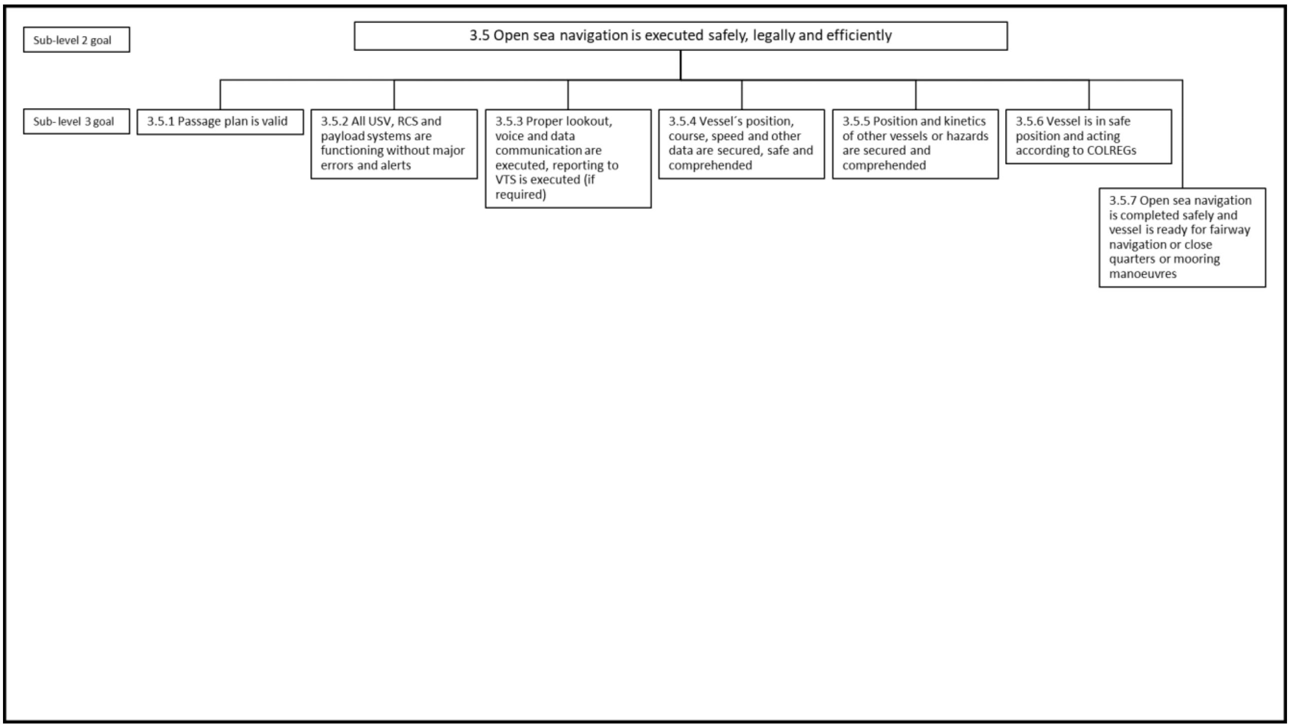

Figure 22: Sub-level goal 3.5, “Open sea navigation is executed safely, legally and efficiently” with sub-level 3 goals.

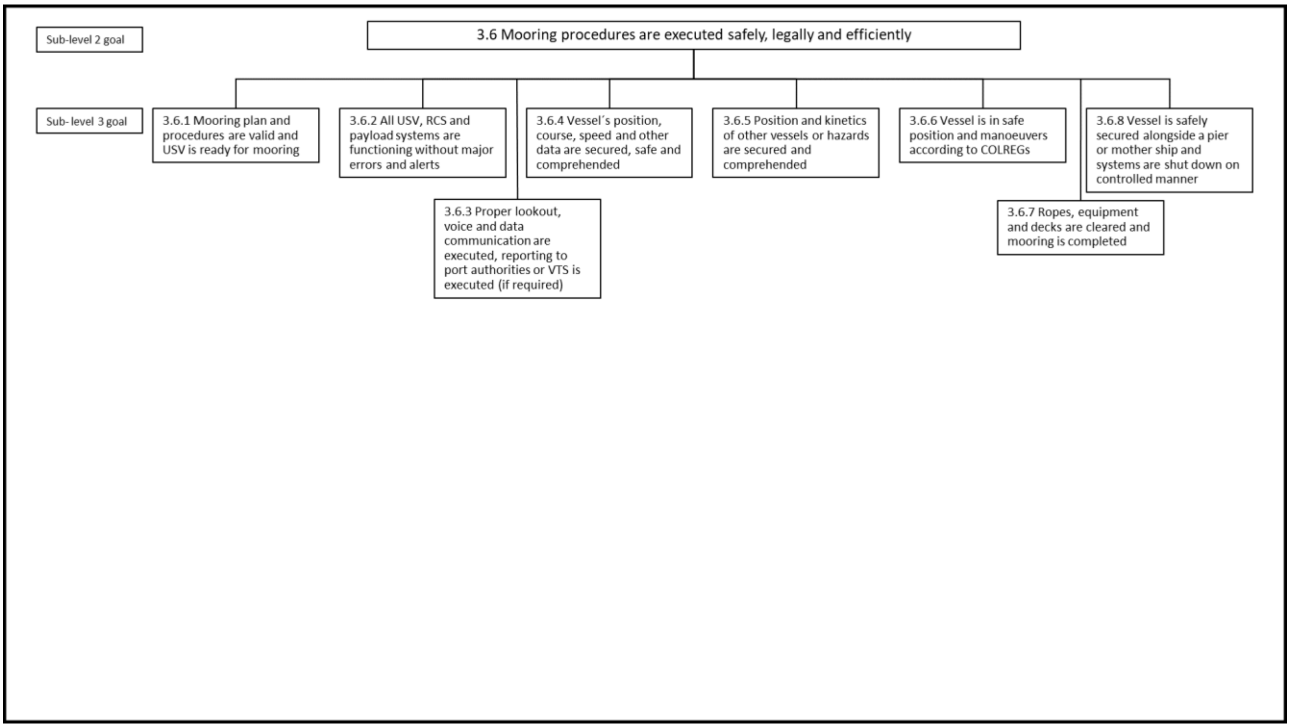

Figure 23: Sub-level goal 3.6, “Mooring procedures are executed safely, legally and efficiently” with sub-level 3 goals.

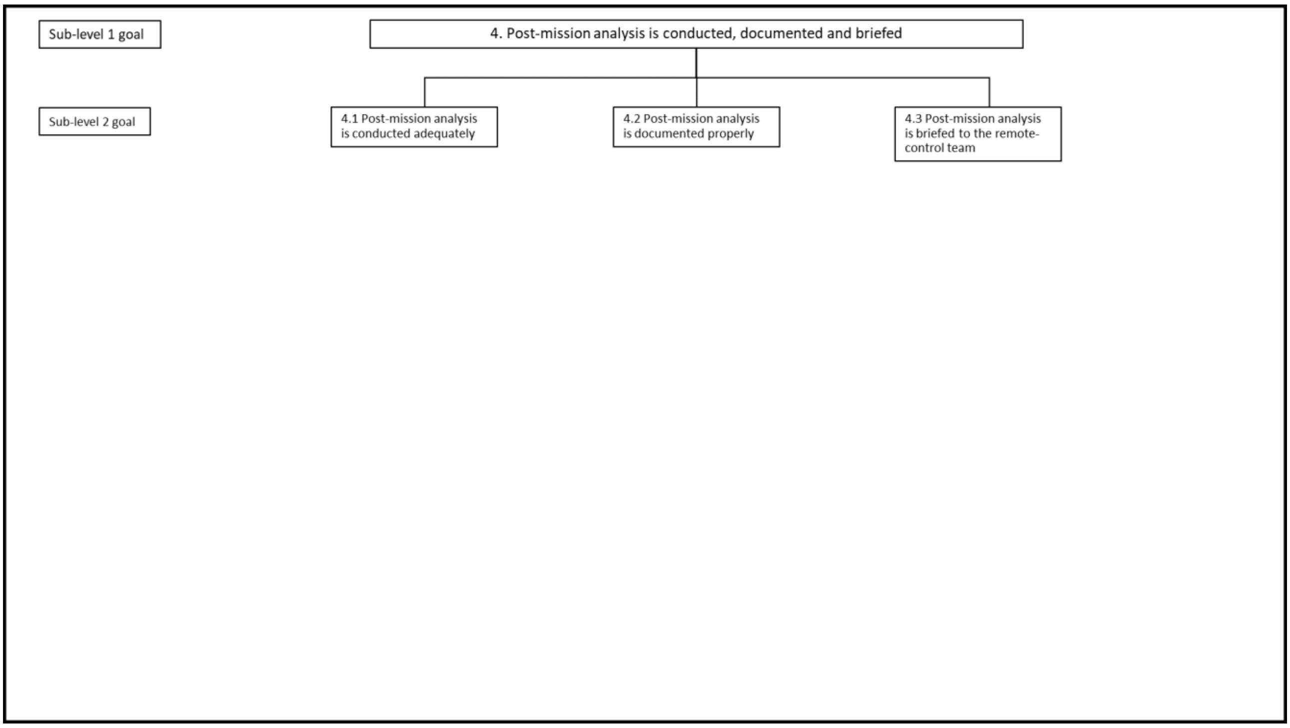

Figure 24: Sub-level goal 4, “Post-mission analysis is conducted, documented and briefed” with sub-level 2 goals.

Appendix 2 The results of the GDTA, information, decisions and requirements for the remote-control system

Appendix 2 contributes to the third research question, “What are the remote-control system operators´ goals and information, decision-making and situation awareness requirements in navigation tasks?” by presenting the operators´ goals analysed in the GDTA.

Appendix 2 contributes also to the fourth research question, “What are system requirements for a remote-control system from user-centred perspective?” by presenting results of the GDTA.

Part 1 of the Appendix consist of 36 groups of information the operators need at minimum to accomplish the goals of planning, preparations and conduct of safe, legal and effective remote vessel operations.

Part 2 of the Appendix presents 92 checks, choices and decisions the operators have to make during planning, preparations and conduct of safe, legal and effective remote vessel operations.

Part 3 of the Appendix includes the main results of the GDTA. It includes 90 requirements for the remote-control system based on the analysis, operators´ information requirements and checks, choices and decisions.

The results of the analysis are divided to three main parts and presented as a combined results to keep the results as comprehensive as possible.

Results include information the operators need, required operators´ checks, choices and decisions and requirements for the remote-control system. Decisions may include of perception of the elements in the environment and situation and concluding yes or no (SA level 1) or decisions require comprehending the current situation (SA level 2). Decisions that require mental processing and results in estimation about future events (SA level 3) are in *Italic*. Situation Awareness levels are based on Endsley´s categories and are presented for every required decision to show which level of SA the system must support the operators to conduct their tasks. Studying results together with goals in chapter seven and hierarchically illustrated goals in Appendix 1 shall improve comprehension of the results.

1. Information the remote operators need to achieve their goals

#	1. Information the remote operators need to achieve their goals
1	Origin and destination (refers to goal 1.1)
2	Mission information and requirements, tasks, constraints and restraints, restrictions, rules of engagement and other mission related factors (goal 1.1)
3	Status of all vessel, payload and remote-control systems (goal 1.1)
4	All passage requirements and appraisal factors (goal 1.1)
5	Weather conditions and forecasts (sea-state, current, wind, rain, ice, visibility) (goal 1.1)
6	Traffic situation and operation area conditions (goals 1-3)
7	Results of risk assessments (goals 1-3)
8	Shallow waters and hazardous areas (goal 1.1)
9	Other risk factors including mission critical equipment and remote emergency and fail-safe procedures, emergency anchoring, dynamic positioning or
10	Required minimum capability and system performance to proceed with the mission at sea (goal 1.1)
11	Availability of required navigation and planning systems e.g. properly functioning ECDIS and/or sea charts (goal 1.2)
12	Cast off, mooring, manoeuvring, navigation, contingency and emergency factors, procedures and checklists (goal 1.3)
13	Payload mission information and requirements, tasks, constraints and restraints, restrictions, rules of engagement and other mission related factors (goal 1.4)
14	Approval of the best and safe route (goal 1.5)
15	Valid and available plans (goals 1-3)
16	Data that all previous procedures are completed successfully and goals have been achieved (goals 1-3)
17	Valid environmental and operational conditions and forecasts (goals 1-3)
18	Status of all vessel, remote-control and payload systems, data and performing (goals 2-3)
19	Data security, quality, accuracy, integrity, errors and delays between all relevant systems on-board vessel and in remote-control system (goals 2-3)
20	Status and readiness of remote-control system manning (goals 2-3)
21	Vessel and control systems data quality and errors (goals 2.2, 2.5 and 3.1-3.6)
22	Level of situation awareness of operators (goals 3.1-3.6)
23	Passage is executed safely, legally and efficiently (goals 3.1-3.6)
24	Efficiency and reliability of monitoring and control (goals 3.1-3.6)
25	Safe position of the vessel at all times (goals 3.1-3.6)
26	Effective and efficient operator team resources and capability management (goals 3.1-3.6)
27	Values of data security, quality, accuracy, integrity, errors and delays between all relevant systems on-board vessel and in remote-control system are on an adequate level (goals 3.1.1-3.6.6)
28	Proper and secured lookout information and data inside and outside the vessel (incl. navigation lights and sound signals) (goals 3.2.3 and 3.3.3-3.6.3)
29	Communication system data and communication with other vessels and ashore (goals 3.2.3 and 3.3.3-3.6.3)
30	Secured data of vessel position, course, speed, water depth, RPM and propulsion data (goals 3.2.4 and 3.3.4-3.6.4)
31	Position of the vessel related to other vessels, obstacles and hazards, CPA and TCPA data (goals 3.2.5- 3.2.6 and 3.3.5-3.6.5)
32	Feedback related to efficiency and timely accuracy of controls (goals 3.2.4-3.2.6, 3.3.4-3.3.8, 3.4.4-3.4.7, 3.5.4-3.5.8 and 3.6.4-3.6.8)
33	Kinetics of other vessels and hazards related to own vessel (goals 3.2.5-3.6.6)
34	Vessel´s safe position, course and speed and status and safe manoeuvers related to the situation and status according to COLREGs (goals 3.2.6-3.6.6)
35	Surveillance data regarding the vessel hull, superstructure and decks (goals 3.1-3.6)
36	Data ensuring that previous goals are completed safely and vessel is ready to proceed (goals 3.1-3.6)

Table 7: The results of the GDTA: Information the remote operators need to achieve their goals.

2. Checks, choices and decisions the operators need to make to achieve the goals

#	2. Checks, choices and decisions the operators need to make to achieve the goals
1	Are all planning material and systems tested and ready for use? (refers to goals 1.1-1.5, decision refers to SA level 1)
2	Are origin, destination, mission and tasks perceived and comprehended correctly? (goal 1.1, SA level 1-2)
3	Are status of all vessel and remote-control systems perceived and comprehended correctly? (goal 1.1, SA level 1-2)
4	Are all relevant appraisal and passage requirements and factors perceived and comprehended correctly? (goal 1.1, SA level 1-2)
5	Are all relevant navigational factors perceived and comprehended correctly? (goal 1.1, SA level 1-2)
6	*How passage requirements, navigational and other appraisal factors effect passage planning? (goals 1.1 - 1.5, SA level 3)*
7	Are all relevant weather conditions and forecasts received, perceived and comprehended correctly? (goal 1.1, SA level 1-2)
8	*How operational, weather and other conditions and forecasts effect passage planning? (goals 1.1 - 1.5, SA level 3)*
9	What is the required minimum capability and system performance to proceed with the mission in current and forecasted weather and other conditions? (goals 1.1 - 1.5, SA level 1-3)
10	What are mission critical equipment and requirements for remote emergency and fail-safe procedures (e.g. emergency anchoring, dynamic positioning or other safety modes or safe return to port)? (goals 1.1 - 1.5, 2-3 SA level 1-2)
11	Are all relevant risk factors perceived and comprehended correctly? (goals 1.1, 2-3, SA level 1-2)
12	Are risk management procedures completed and are risks assessed adequately? (goals 1.1, 2-3, SA level 1-2)
13	*How risks factors effect passage planning and execution of operations? (goals 1.1, 2-3, SA level 3)*
14	Is passage plan defined, evaluated, selected and comprehended? (goal 1.2, SA level 2)
15	Are all necessary changes to the plans defined and completed? (goal 1.2, SA level 1)
16	Are all required cast off, manoeuvring, navigation, mooring, contingency and emergency factors, procedures and checklists defined and comprehended? (goal 1.3, SA level 1-2)
17	Are plans to conduct payload mission and tasks completed successfully? (goal 1.4, SA level 1)
18	Is payload operation plan defined, evaluated, selected and comprehended? (goal 1.4, SA level 2)
19	Is passage planning completed successfully? (goal 1.5, SA level 1)
20	Is passage plan approved by the Master and briefed to the remote-control team? (goal 1.5, SA level 1)
21	Will the passage plan enable safe passage to destination and back? (goals 1.1-1.5, SA level 2)
22	Are all vessel, payload and remote-control systems tested and ready for use? (goal 2.2, SA level 1-2)
23	Are all system tests and checks completed, are they documented to predefined checklists and recorded? (goal 2.2, SA level 1-2)
24	Are all vessel, payload and remote-control systems functioning properly without errors and alerts? (goals 2.2-2.6, SA level 1-2)
25	What is the acceptable level of errors and alerts, the individual or combined effect of them to conduct safe, legal and efficient operations? (goals 2.2-2.6, 3.1-3.6, SA level 1-2)
26	*How does the vessel, payload and remote-control systems perform? (goals 2.2 -2.6, 3.1-3.6, SA level 3)*
27	Is remote-control system properly manned and crew on-board if required? (goal 2.4, SA level 1)
28	Does the systems performance fulfil the sufficient level of functioning configuration of systems to safely, legally and efficiently conduct operations? (goals 2.2-2.6, SA level 1-2)
29	Are pre-departure procedures completed successfully? (goals 2.1 -2.6, SA level 1-2)
30	Is the vessel ready for going to the sea? (goals 2.1 -2.6, SA level 1-2)
31	Are all preceding plans, procedures and goals completed successfully? (goals 1-2, SA level 1)
32	Are all preceding plans valid and if not how do they need to be altered? (goals 1-2, SA level 1-2)
33	*How preceding plans and procedures effect execution of safe, legal and efficient operations (pre-departure procedures, vessel operations, cast off, close quarters manoeuvring, fairway navigation, open sea navigation, payload operations and mooring)? (goals 1-3, SA level 3)*
34	Do preceding plans, procedures and passage enable safe, legal and efficient operations? (goals 1-3, SA level 1-2)
35	*How weather, environmental, operational conditions and forecasts effect execution of safe, legal and efficient operations? (goals 1-3, SA level 3)*
36	What is the minimum and sufficient level of functioning configuration of systems to safely, legally and efficiently conduct operations in current and forecasted weather and other conditions? (goals 2.2-2.6, 3.1-3.6, SA level 1-2)
37	Do all systems provide high quality data to enable safe, legal and efficient remote monitoring and control? (goals 3.1-3.6, SA level 1-2)
38	Is received data from the vessel secured and reliable with high level of data quality, accuracy and integrity with minimal errors and delays? (goals 3.1-3.6, SA level 1-2)
39	Are data security, quality, accuracy, integrity, errors and delays between all relevant systems on-board the vessel and in remote-control system on an adequate level? (goals 3.1.1-3.1.2, 3.2.2-3.2.6, 3.3.2-3.3.6, 3.4.2-3.4.6, 3.5.2-3.5.6 and 3.6.2-3.6.6, SA level 1-2)
40	Does the quality of data received form the vessel enable safe, legal and efficient remote monitoring and control? (goals 3.1-3.6, SA level 1-2)
41	*How the quality of data, data errors or delays effect safe, legal and efficient operations currently and in the near future? (goals 3.1-3.6, SA level 3)*
42	Do operators have sufficient situation awareness for safe, legal and efficient remote operations? (goals 3.1.3, 3.1-3.6, SA level 1-2)
43	Is communication to other vessels and ashore conducted on a proper manner? (goals 3.1.3-3.6.3, SA level 1-2)
44	Do operators perceive all elements and risks in the environment, comprehend the current situation and project the future status adequately? (goals 3.1.3, 3.1-3.6, SA level 1-2)
45	Do operators share situation awareness efficiently? (goals 3.1.3, 3.1-3.6, SA level 1-2)
46	Do operators make correct and timely accurate decisions based on adequate situation awareness and risk assessment? (goals 3.1.3, 3.1-3.6, SA level 1-2)
47	How does operators´ situation awareness effect safe remote operations currently and in the near future? (goals 3.1.3, 3.1-3.6, SA level 3)
48	Are all systems continuously under efficient and reliable monitoring and control? (goals 3.1.4, 3.1-3.6, SA level 1-2)
49	Do operators monitor all systems efficiently and are they in the loop during the operation? (goals 3.1.4, 3.1-3.6, SA level 1- 2)
50	Do operators control all systems efficiently with minimal errors and delays? (goals 3.1.4, 3.1-3.6, SA level 1-2)

#	**2. Checks, choices and decisions the operators need to make to achieve the goals**
51	Do systems enable vessel's efficient remote fire and damage control? (goals 3.1.4, 3.1-3.6, SA level 1-2)
52	Do systems enable remote emergency or fail-safe procedures (e.g. anchoring, dynamic positioning, other safety modes or safe return to port)? (goals 3.1.4, 3.1-3.6, SA level 1-2)
53	*How well does conducted monitoring and controlling ensure safe operations currently and in the near future? (goals 3.1.4, 3.1-3.6, SA level 3)*
54	Is vessel in safe position related to other vessels and hazards and acting according to COLREGS currently and the near future? (goals 3.1.5, 3.1-3.6, SA level 1-3)
55	Are the operator team resources managed effectively and efficiently? (goals 3.1.5, 3.1-3.6, SA level 1-2)
56	Are operations and systems optimised according to team´s competency and reliability? (goals 3.1.6, 3.1-3.6, SA level 1-2)
57	Is the operator team communicating and informed on a sufficient manner? (goals 3.1.6, 3.1-3.6, SA level 1-2)
58	*How does the operator team management and communicating impact to safe operations currently and in the near future? (goals 3.1.6, 3.1-3.6, SA level 3)*
59	Are all relevant risks and unknown factors defined, assessed, perceived, comprehended and addressed properly? (goals 3.1-3.6, SA level 1-2)
60	Are risks and effects to operations minimised? (goals 3.1-3.6, SA level 1)
61	Are system and operator abnormalities minimised? (goals 3.1-3.6, SA level 1)
62	*How risks effect safe, legal and efficient operations currently and in the near future? (goals 3.1-3.6, SA level 3)*
63	*How well does the near future projection regarding position, course, speed, other vessels, obstacles, hazards, weather, other conditions and tasks ensure safe operations? (goals 3.1-3.6, SA level 3)*
64	Have all relevant safety factors been assessed, perceived and addressed on a sufficient manner? (goals 3.1-3.6, SA level 1-2)
65	How do relevant safety factors impact to safe operations currently and in the near future? (goals 3.1-3.6, SA level 3)
66	Are all vessel operations conducted in a safe, legal and efficient manner? (goals 3.1-3.6, SA level 1-2)
67	Are all vessel, remote-control and payload systems performing properly without errors and alerts? (goals 3.1-3.6, SA level 1-2)
68	How do the vessel and the remote-control system perform? (goals 3.1-3.6, SA level 2)
69	*How performing of systems, including errors and alerts effect execution of safe, legal and efficient operations? (goals 3.1-3.6 SA level 3)*
70	Are all required stations manned properly to conduct safe, legal and efficient operations (goals 3.1-3.6, SA level 1-2)
71	Is proper lookout executed and does lookout provide adequate information? (goals 3.1-3.6, SA level 1)
72	*How lookout information effect execution of safe, legal and efficient operations? (goals 3.1-3.6, SA level 3)*
73	Is communication to other vessels and ashore conducted on a proper manner? (goals 3.1-3.6, SA level 1-2)
74	Are position, course and speed of the vessel secured and comprehended correctly? (goals 3.1-3.6, SA level 1-2)
75	Are data security, quality, accuracy, integrity, errors and delays between all relevant systems on-board the vessel and remote-control system on an adequate level? (goals 3.1-3.6, SA level 1-2)
76	Is received data from the vessel accurate, reliable and time relevant? (goals 3.1-3.6, SA level 1-2)
77	Is received data from the vessel perceived and comprehended properly? (goals 3.1-3.6, SA level 1-2)
78	Is it required for operators to take over control from the automatic navigation system (if applicable)? (goals 3.1.4-3.1.5 and 3.1-3.6, SA level 1-2)
79	*How much it is required to control speed and course to port/starboard? (goals 3.1-3.6, SA level 2-3)*
80	*How are safe evasive manoeuvring conducted? (goals 3.1-3.6, SA level 3)*
81	Are position and kinetics of other vessels or hazards perceived and comprehended correctly? (goals 3.1-3.6, SA level 1-2)
82	Are CPA and TCPA determined, perceived and comprehended correctly? (goals 3.1-3.6, SA level 1-2)
83	*How position and kinetics of own vessel and other vessels or hazards effect manoeuvring? (goals 3.1-3.6, SA level 3)*
84	Is vessel in safe position? (goals 3.1-3.6, SA level 2)
85	Is the vessel a give-way or stand-on vessel related to other vessels? (goals 3.1-3.6, SA level 2)
86	Is the vessel manoeuvring according to COLREGs? (goals 3.1-3.6, SA level 2)
87	Are position and kinetics of other vessels or hazards safe related to own vessel in the near future? (goals 3.1-3.6, SA level 3)
88	Is it safe to proceed? (goals 1-3, SA level 1-2)
89	*What will happen next and in the near future? (goals 1-3, SA level 3)*
90	Are all operations (cast off, close quarters manoeuvring, fairway and open sea navigation and mooring) completed in safe, legal and efficient manner? (goals 3.1-3.6, SA level 1)
91	Is vessel safely secured alongside a pier or mother ship? (goal 3.6, SA level 1)
92	Are all systems shut down on controlled manner? (goal 3.6, SA level 1)

Table 8: The results of the GDTA: Checks, choices and decisions the operators need to make to achieve the goals.

3. Requirements for the remote-control system

The remote-control system shall support the operators´ assessment, decision-making and conduct of planning, preparations, execution and recording of all remote vessel operations by including, interfacing, providing or enabling following requirements.

#	3. Requirements for the remote-control system
1	Include or interface to an effective planning system for passage planning (refers to goals 1.1-1.5)
2	Present, display and record origin, destination, mission and tasks and support assessment of how they effect on planning (goal 1.1)
3	Present, display and record status of all vessel and remote-control systems correctly (goal 1.1)
4	Enable and support the appraisal process and present appraisal process results (goal 1.1)
5	Support assessment regarding completion and comprehension of appraisal factors (goal 1.1)
6	Gather and present all relevant weather conditions and forecasts (goal 1.1)
7	Support assessment of how weather conditions and forecasts effect passage planning (goal 1.1)
8	Enable and support effective risk assessment and risk management procedures (goals 1.1, 2.1.6 and 3.1-3.6)
9	Present, display and record risk factors and areas, risk assessment results and effects to execution of safe, secure and efficient vessel operations (goals 1.1, 2.1.6 and 3.1-3.6)
10	Provide means to ensure that unknown factors are defined and assessed (goals 1.1, 2.1.6 and 3.1-3.6)
11	Support assessment of what is required minimum capability and system performance to proceed with the mission in current weather and other conditions and present, display and record the information (goal 1.1)
12	Support assessment of what are what are mission critical equipment and requirements for remote emergency or fail-safe procedures (e.g. emergency anchoring, hovering, other safety modes or safe return to port) and present, display and record the information (goal 1.1)
13	Support assessment of what are risk factors and areas, risk assessment results and effects to passage and present, display and record the information (goal 1.1)
14	Support defining, evaluating and selecting the passage plan (goal 1.2)
15	Support assessment of completion of all necessary changes to the passage plan and operators´ comprehension of the passage plan (goal 1.2)
16	Support establishment and comprehension of cast off, mooring, manoeuvring, navigation, contingency and emergency factors, plans, procedures and checklists (goal 1.3)
17	Support assessment of quality and completion of payload mission planning (goal 1.4)
18	Support assessment of does the passage plan provide safe passage to destination and back and is it safe to proceed according to plan (goals 1.1-1.4)
19	Support assessment of quality, validity and completion of passage planning (goals 1.1-1.4)
20	Support approval and briefing of the passage plan and record that the plan is approved and briefed to the remote-control team (goal 1.5)
21	Support assessment of how weather and operational conditions and forecasts effect pre-departure procedures and execution of safe, legal and efficient operations (goals 2.1.1-2.15, 3.1-3.6)
22	Present, display and record the results of all vessel systems tests and status of readiness for use (goals 2.2.1–2.2.2 and 3.1-3.6)
23	Support assessment of how all systems on-board the vessel and remote-control systems are performing (goals 2.2, 2.3, 2.5, 2.6 and 3.1-3.6)
24	Present, display and record that all vessel, remote-control and payload systems are performing properly without errors and alerts (goals 2.2, 2.5, 2.6 and 3.1-3.6)
25	Support assessment of how all vessel, remote-control and payload systems are performing (goals 2.2, 2.3, 2.5, 2.6 and 3.1-3.6)
26	Present, display and record that remote-control system is properly manned and crew is on-board if required (goals 2.4 and 3.1-3.6)
27	Present, display and record that all system tests and checks are completed and documented to predefined checklists (goals 2.2 -2.6)
28	Support assessment that pre-departure procedures are completed successfully (goals 2.1-2.6)
29	Support assessment that pre-departure procedures provide safe passage to destination and back (goals 2.1-2.6)
30	Support assessment that the vessel is ready for going to the sea and that it is safe to proceed (goals 2.1-2.6)
31	Present, display and record the vessel´s readiness for going to the sea (goals 2.1-2.6)
32	Support assessment that all vessel, remote-control and payload systems are functioning without major errors and alerts (goals 2.2-2.6, 3.1.2.-3.5.2 and 3.1.1)
33	Present, display and record the minimum sufficient level of functioning configuration of systems to conduct vessel operations safely, securely, legally and efficiently (goals 2.2-2.6, 3.1.1.-3.5.2)
34	Present, display and record that the data security, quality, accuracy, integrity, errors and delays between all relevant systems on-board the vessel and remote-control system are on an adequate level and enable safe, secure and efficient remote monitoring and control (goals 2.2-2.5 and 3.1.2 -3.6.2)
35	Support assessment that the received data is secured and reliable with high level of data quality, accuracy and integrity and with acceptable level of errors and delays (goals 2.2-2.5 and 3.1.2 -3.6.2)
36	Support assessment that operators have sufficient situation awareness for safe, legal and efficient remote operations (pre-departure procedures, vessel operations, cast off, close quarters manoeuvring, fairway navigation, open sea navigation, payload operations and mooring) (goals 3.1.3 and 3.1-3.6)
37	Support assessment that operators perceive all elements and risks in the environment, comprehend the current situation and project the future status adequately (goals 3.1.3 and 3.1-3.6)
38	Ensure that operators can share situation awareness efficiently (goals 3.1.3 and 3.1-3.6)
39	Support operators to make correct and timely accurate decisions based on adequate situation awareness and risk assessment (goals 3.1.3 and 3.1-3.6)
40	Support assessment of how operators´ situation awareness effect safe remote operations currently and in the near future (goals 3.1.3 and 3.1-3.6)
41	Support assessment that all systems are continuously under efficient and reliable monitoring and control (goals 3.1.4 and 3.1-3.6)
42	Support operators to monitor all systems efficiently and keeping operators in the loop during all operations (goals 3.1.4 and 3.1-3.6)
43	Support operators to assess is it required to take over control from the automatic navigation system (if applicable) (goals 3.1.4-3.1.6 and 3.1-3.6)
44	Ensure safe, secure and efficient remote-control of speed and course (goals 3.1.4-3.1.5 and 3.2.6-3.6.6)
45	Ensure safe, secure and efficient remote full stop, crash stop and reversing the vessel when required (goals 3.1.4-3.1.5, 3.2.6-3.6.6 and 3.1-3.6)
46	Support operators to control all systems efficiently with minimal errors and delays (goals 3.1.4 and 3.1-3.6)

#	3. Requirements for the remote-control system
47	Ensure that systems enable vessel's safe, legal and efficient remote fire and damage control (goals 3.1.4 and 3.1-3.6)
48	Ensure that systems enable safe, legal and efficient fail-safe and remote emergency procedures, anchoring, dynamic positioning, other safety modes or safe return to port (goals 3.1.4 and 3.1-3.6)
49	Support assessment of how well conducted monitoring and controlling ensure safe, legal and efficient operations currently and in the near future (goals 3.1.4 and 3.1-3.6)
50	Support assessment that the is vessel in safe position related to other vessels and hazards and acting according to COLREGS at all times (goals 3.1.5, 3.2.6-3.5.6 and 3.1-3.6)
51	Support assessment that the operator team resources are managed effectively and efficiently (goals 3.1.6 and 3.1-3.6)
52	Support assessment that operations and systems are optimized according to team´s competency and reliability (goals 3.1.6 and 3.1-3.6)
53	Ensure that the operator team can communicate on a sufficient manner (goals 3.1.6 and 3.1-3.6)
54	Support assessment of how the operator team management and communicating effect safe, legal and effective operations currently and in the near future (goals 3.1.6 and 3.1-3.6)
55	Support assessment that risks and unknown factors are defined or assessed, perceived and addressed properly (goals 3.1.6 and 3.1-3.6)
56	Ensure and support assessment that risks and effects to operations are minimised (goals 3.1.6 and 3.1-3.6)
57	Ensure and support assessment that systems´ and operators´ abnormalities are minimized (goals 3.1.6 and 3.1-3.6)
58	Support assessment of how well the near future projection regarding position, course, speed, other vessels, obstacles, hazards, weather, other conditions and tasks ensure safe, legal and effective operations (goals 3.1.6 and 3.1-3.6)
59	Support assessment that all relevant safety factors have been assessed, perceived and addressed on a sufficient manner (goals 3.1.6 and 3.1-3.6)
60	Support assessment of how relevant safety factors effect safe, legal and effective operations currently and in the near future (goals 3.1.6 and 3.1-3.6)
61	Ensure and support assessment that operations are conducted in a safe, legal and efficient manner (goals 3.1.-3.6)
62	Support assessment to ensure that preceding plans and procedures are completed successfully and provide safe, legal and efficient operations (goals 1-
63	Support assessment of how systems performing, errors and alerts effect safe, legal and efficient operations (goals 2.2, 2.5, 2.6 and 3.1-3.6)
64	Execute proper lookout and support assessment that lookout provides adequate information (goals 3.2.3-3.6.3, 3.1-3.6)
65	Support assessment to determine how lookout information effect safe, legal and efficient operations (goals 3.1.3, 3.2.3-3.6.3 and 3.1-3.6)
66	Enable communication to other vessels and ashore including reporting to port authorities or VTS on an adequate manner (goals 3.2.3-3.6.3 and 3.1-3.6)
67	Enable efficient communication within remote- control system operators (goals 3.1.6 and 3.1-3.6)
68	Support assessment that received data from the vessel is accurate, reliable and time relevant (goals 3.1.3-3.1.5 and 3.1-3.6)
69	Support assessment that vessel´s position, course and speed and other data is secured, perceived and comprehended properly (goals 3.1.4-3.1.5, 3.2.6-3.6.6 and 3.1-3.6)
70	Ensure safe, secure and efficient taking over the control from the automatic navigation system (if applicable) (goals 3.1.4-3.1.6 and 3.1-3.6)
71	Support assessment of how much it is required to control speed and course to port/starboard (goals 3.1.4-3.1.5, 3.2.6-3.6.6 and 3.1-3.6)
72	Enable safe and secure and efficient remote-control of speed and course to port and starboard (goals 3.1.4-3.1.5, 3.2.6-3.6.6 and 3.1-3.6)
73	Support assessment of how are safe evasive manoeuvring conducted (goals 3.1.4-3.1.5, 3.2.6-3.6.6 and 3.1-3.6)
74	Enable safe and secure and efficient remote full stop, crash stop and reversing the vessel when required (goals 3.1.4-3.1.5, 3.2.6-3.6.6 and 3.1-3.6)
75	Enable safe and secure and efficient fail-safe and emergency procedures if required (goals 1.3 and 3.1-3.6)
76	Support assessment of are position and kinetics of other vessels or hazards perceived and comprehended correctly (goals 3.1.4-3.1.5, 3.2.5-3.6.5 and 3.1-3.6)
77	Support assessment that CPA and TCPA are determined, perceived and comprehended correctly (goals 3.1.4-3.1.5, 3.2.5-3.6.5, 3.2.6-3.6.6 and 3.1-
78	Support assessment of is the vessel a give-way or stand-on vessel related to other vessels (goals 3.1.4-3.1.5, 3.2.5-3.6.5, 3.2.6-3.6.6 and 3.1-3.6)
79	Support assessment that the vessel is in safe position (goals 3.1.4-3.1.5, 3.2.6-3.6.6 and 3.1-3.6)
80	Support assessment that the vessel is manoeuvring according to COLREGs (goals 3.1.4-3.1.5, 3.2.6-3.6.6 and 3.1-3.6)
81	Support assessment that position and kinetics of other vessels or hazards are safe related to own vessel in the near future (goals 3.1.4-3.1.5, 3.2.5-3.6.5, 3.2.6-3.6.6 and 3.1-3.6)
82	Support assessment that all ropes, equipment and deck are cleared (goal 3.2.7 and 3.1-3.6)
83	Support assessment that previous goals and operation phases are achieved on safe, legal and efficient manner (goals 3.2.8 and 3.1-3.6)
84	Support assessment that the vessel is ready for the next operation phase and to achieve next goals on safe, legal and efficient manner (goals 3.1-3.6)
85	Support assessment that it is safe to proceed (goal 3.2.8 and 3.1-3.6)
86	Support assessment of what will happen in near future regarding position, course, speed, other vessels, obstacles, hazards, weather, other conditions and tasks (goals 3.1.4-3.1.5, 3.2.4-3.2.6, 3.2.5-3.6.5, 3.2.6-3.6.6 and 3.1-3.6)
87	Support assessment that mooring is completed safely (goal 3.6.7)
88	Support assessment that the vessel is safely secured alongside a pier or mother ship (goal 3.6.7)
89	Support assessment that systems are shut down on controlled manner (goal 3.6.8)
90	Support assessment of what will happen in near future and is it safe to proceed (goals 1-3)

Table 9: The results of the GDTA: Requirements for the remote-control system.

Appendix 3 Interview questions and workshop topics

Semi-structured interview questions for subject matter experts. These questions form topics for all workshops conducted with SME´s.

1. Background

- What is your experience in navigation?

- What is your experience in navigation system design and/or projects?

- What is your experience in remote-control of the vessels?

2. Navigation functions, tasks and goals

- What is the overall mission of the USV remote navigation?

- What tasks and possible sub-tasks are conducted during remote navigation?

- What are the operators´ goals relevant to successful job performance in remote navigation?

- What are the operators´ sub-goals relevant to successful job performance related to goals in remote navigation?

- What are the information requirements relevant to successful job performance related to goals in remote navigation?

- What kind of decisions the remote operators have to make in order to achieve the goals?

- Why are these decision required?

- What are requirements for the remote-control system to support the operators´ decision-making and provide means to successfully conduct operations, achieve goals and accomplish the overall mission?

Appendix 4 Definitions and explanations

Definitions and explanations used in the thesis are presented in the following table.

Definition	Explanation	Source
Appraisal, Automation, Autonomy		
Appraisal	Appraisal includes collecting and assessing all relevant information required for the intended passage. The act of examining someone or something in order to judge their qualities, success, or needs.	Bridge Procedures: the importance of passage planning Cambridge dictionary
Automatic	Pertaining to a process or device that, under specified conditions, functions without human intervention.	ISO/TR 11065 and Maritime UK
Automation	An apparatus, process, or system that is self-acting or self-regulating, generally through the employment of mechanical or electrical devices that replace human observation, effort and decision-making The automatically-controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human labour. Automation is not self-directed, but instead requires command and control (a pre-planned set of instructions). A system can be automated without being autonomous.	Babicz, Wärtsilä encyclopedia of ship technology Merriam-Webster dictionary NASA Autonomous systems capability overview
Automation system	System based on one or more devices whose implementation can be adjusted in advance, including, where appropriate, devices whose behaviour depends on unforeseeable factors. An automation system can be composed of various types of devices: mechanical, electrical, digital, electronic, magnetic, hydraulic or other. An automation system may be used, for example, for control, protection, lookout, recording or monitoring functions.	BV Guidelines for Autonomous Shipping
Autonomous	Something that is undertaken or carried on without outside control, existing or capable of existing independently or responding, reacting, or developing independently of the whole.	Merriam Webster dictionary
Autonomous ship Autonomous Ship System	A marine vessel with sensors, automated navigation, propulsion and auxiliary systems, with the necessary decision logic to follow mission plans, sense the environment, adjust mission execution according to the environment, and potentially operate without human intervention. All physical and human elements that together ensure sustainable operation of an autonomous ship in its intended operations or voyage.	American Bureau of Shipping Maritime UK
Autonomy	Autonomy is a capability (or a set of capabilities) that enables a particular action of a system to be automatic or, within programmed boundaries, “self-governing.” Autonomy could be the UMV’s own ability of sensing, perceiving, analysing, communicating, planning, decision-making, and acting, to achieve its goals as assigned by its human Controller(s). In the context of ships, autonomy (e.g. as in "Autonomous Ship") means that the ship can operate without human intervention, related to one or more ship functions, for the full or limited periods of the ship operations or voyage.	EDA SARUMS Maritime UK

Definition	Explanation	Source
Autonomy, Autoremote, Awareness		
Autonomy	Autonomy is about making systems self-directed and self-sufficient, not only about making systems adaptive, intelligent, smart or unmanned * Systems can include humans as an integral element (human-system integration and interaction, human-autonomy teaming) * Software (e.g., decision support) can make humans more autonomous of other humans (air traffic control, mission control) Autonomy may use artificial intelligence * Machine learning (deep learning, reinforcement learning) * Perception (object recognition, speech recognition, vision) * Search, probabilistic methods, classification, neural networks. Autonomy often relies on automation * Most robotic space missions rely on automation * Command sequencing (event, order, time triggered) The right or condition of self-government.	NASA Autonomous systems capability overview Oxford dictionary
Autoremote	To denote any operation, task, function or system where the intention is to create additional decision support, remote-control, or autonomous functionality compared to a conventional, crewed ship.”	DNV GL class guideline, autonomous and remote operated ships
Awareness	The quality or state of being aware, knowledge and understanding that something is happening or exists.	Merriam Webster dictionary
Back-up control systems, Bureau Veritas		
Back-up control systems	Back-up control systems comprise all equipment necessary to maintain control of essential functions required for the craft's safe operation when the main control systems have failed or malfunctioned.	BV rules for classification of high speed craft
Bureau Veritas	Bureau Veritas is a society with the purpose is the classification of any ship or vessel or structure of any type or part of it or system therein collectively linked to shore, river bed or sea bed etc. The Society prepares and publishes Rules for classification, Guidance Notes and other documents, issues Certificates and Reports and publishes Registers.	BV rules for classification of high speed craft remote-control alarm and safety systems.
Collision Regulations, Command, Console		
Collision Regulations	Collision Regulations (COLREG 1972) – The Convention on International Regulations for Preventing Collision at Sea adopted in 1972 by IMO.	Babicz, Wärtsilä encyclopedia of ship technology
Command	The authority vested in an individual of the armed forces for the direction, coordination, and control of military forces. To direct authoritatively, to exercise a dominating influence over, to demand or receive as one's due, to have military command of as senior officer.	Future of Command and Control, NATO term Merriam Webster dictionary
Command and Control	An institutional, compound and contested term. It can be a process, a capability, a system or a structure. It can also be treated as a single whole, 'command and control', with a different meaning to the separate words 'command' and 'control'.	Future of Command and Control, NATO term
Commanding Officer	A person who commands a warship or military UMV, who is duly commissioned by the government of the State and whose name appears in the appropriate service list or its equivalent in accordance with article 29 UNCLOS regarding a warship. This person may be located anywhere provided that the required method of control and communication can be maintained to discharge the duties arising out of such commission.	EDA SARUMS
Console	A control panel, often the central unit, from which an operator can operate and supervise machinery or equipment.	Babicz, Wärtsilä encyclopedia of ship technology

Definition	Explanation	Source
Control, Control and Communication Centre, Controller, Control position		
Control	The process of conveying a command or order to affect the desired action.	American Bureau of Shipping
	The process of conveying a command or order to enable the desired action to be done. *Automatic control means of control that conveys predetermined orders without operator action. *Local control is a device or a station located on or close to a machine to enable its operation within sight of the operator. * Remote-control is a device or array of devices connected to a machine by mechanical, electrical, pneumatic, hydraulic or other means and by which the machine may be operated remotely from, and not necessarily within sight of the operator.	Babicz, Wärtsilä encyclopedia of ship technology
	Controlling a ship consists in operating devices related to its navigation or its operations. Ships may be controlled either by the crew, or remotely by operators, or by automation systems with or without human interaction.	BV Guidelines for Autonomous Shipping
	Control is the authority exercised by a commander over part of the activities of subordinate organisations, or other organisations not normally under his command that encompasses the responsibility for implementing orders or directives.	Future of Command and Control, NATO term
	To exercise restraining or directing influence over, to have power over or power or authority to guide or manage.	Merriam Webster dictionary
Control and Communication Centre	The system provides a vital link between the bridge and the ship's automation, engines, and propulsion control systems. 3C consists of multifunction displays covering full workstations with radar, ECDIS and conning, various sensors for target detection, heading, position and further navigation data with standardised user interfaces.	Babicz, Wärtsilä encyclopedia of ship technology
Controller	Role assumed by the person performing remote-control or tele-operation, semi-autonomous operations, or other man-in-the-loop types of operations. The controller's input is expected at certain stages during normal operations. The Controller may report to either a Watch Officer or the Commanding Officer (Master) depending on the constitution of the control function and the required method of control.	EDA SARUMS
	A person undertaking control functions appropriate for the Level of Control of the MASS. The controller may report to either a Watch Officer or the Master depending on the constitution of the control function, the MASS category and the required Level of Control.	Maritime UK
	One that controls or has power or authority to control.	Merriam Webster dictionary
Control position	A location on the ship/seagoing vessel/watercraft during any periods of manned operation from which control of propulsion, steering and other systems can be exercised	Maritime UK

Definition	Explanation	Source
Control Station, Control system, Course, Crew and Crewless ship		
Control station	The space in which the ship radio or the main navigating equipment or the emergency source of power is located, or where the fire recording or fire control equipment is centralized, (SOLAS). Centralized control station is a propulsion control station fitted with instrumentation, control systems and actuators to enable propulsion and auxiliary machinery be controlled and monitored, and the state of propulsion machinery space be monitored, without the need of regular local attendance in the propulsion machinery space	Babicz, Wärtsilä encyclopedia of ship technology
	A single or multiple position including all equipment such as computers and communication terminals and furniture at which control and monitoring functions are conducted (ISO 11064-3).	BV Guidelines for Autonomous Shipping
	Control station means the set of equipment and control units that are needed at the site where remote-control and/or monitoring of the platform is conducted. The Control station may be located on-board a dedicated ship (GCP), vessel of opportunity or land based such as on a quay, other shore site, supply station on the coast or on a stationary off-shore plant. It may be stationary, integrated to other systems or highly modular and portable.	EDA SARUMS
Control system	An assembly of devices interconnected or otherwise coordinated to convey the command or order.	American Bureau of Shipping
	An arrangement of elements interconnected and interacting in order to maintain, or to affect in a prescribed manner, some condition of a body, process or machine, which forms part of the system.	Babicz, Wärtsilä encyclopedia of ship technology
	The control system includes any systems on-board the UMS and any off-board facility that performs a monitoring and/or control function of propulsion, manoeuvring and navigation systems and the transmission of data to carry out these functions. It does not include monitoring and/or control of auxiliary and mission systems.	LR ShipRight
Course	The intended direction of vessel movement.	Babicz, Wärtsilä encyclopedia of ship technology
Crew	A person employed or engaged in any capacity on-board a ship on the business of the ship or any person engaged in the direct control and operation of the ship from a remote location.	Maritime UK
Crewless Ship	A ship with no crew on-board. Crew does not include passengers, special personnel etc.	Maritime UK
Decision, Decision-making, Det Norske Veritas		
Decision	A choice that you make about something after thinking about it or the result of deciding.	Merriam Webster dictionary
Decision-making	Task in which a person must select one option from several alternatives, a person must interpret information for the alternatives, the timeframe is longer than a second and the choice includes uncertainty.	Designing for People
Det Norske Veritas	DNV is an independent expert in assurance and risk management that aims to safeguard life, property and the environment. DNV is a classification society and an advisor for the maritime industry that deliver testing, certification and technical advisory services to the energy value chain including renewables, oil and gas, and energy management.	DNV

Definition	Explanation	Source
Emergency Stop, Ergonomics, Evaluation		
Emergency Stop	The ability to reduce propulsion to a safe state in a timely manner. A safe state means a level at which it is not likely to cause damage either directly or indirectly. In a timely manner means within a time that is short enough to ensure that the risk from uncontrolled propulsive power can be contained before it is likely to cause damage. Full Shut Down means the ability to turn off all systems as required on the MASS remotely.	Maritime UK
Ergonomics	Application of the human factor in the analysis and design of equipment and working environment. The aim is to improve efficiency and the health and comfort of those working.	Babicz, Wärtsilä encyclopedia of ship technology
Evaluation	The process of judging or calculating the quality, importance, amount, or value of something.	Cambridge dictionary
Fail safe, Function		
Fail safe	A design feature or practice that in the event of a specific type of failure, inherently responds in a way that will cause no or minimal harm to other equipment, to the environment or to people.	Maritime UK
Function	A group of tasks, duties and responsibilities necessary for vessel operation, safety of life at sea or protection of the marine environment.	American Bureau of Shipping
Guideline		
Guideline	Information intended to advise people on how something should be done or what something should be:	Cambridge dictionary
Hazard, Human factors, Human Machine Interaction		
Hazard	Any source of potential damage or casualty, or any situation with potential to cause it.	BV Guidelines for Autonomous Shipping
Human factors	A scientific discipline concerned with the understanding of the interactions among human and the other elements of the system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.	Porathe et al. Situation Awareness in remote-control centres for unmanned ships
Human-Machine Interface (HMI)	Hardware or software through which an operator interacts with a controller. An HMI can range from a physical control panel with buttons and indicator lights to an industrial PC with a colour graphics display running dedicated HMI software.	NIST
Human–machine interaction	Communication and interaction between a human and a machine via a user interface.	Computer Vision for Assistive Healthcare
Information, International Maritime Organisation, International Standardisation Organisation		
Information	Information is knowledge obtained from investigation, study or instruction, Intelligence, news, facts or data. The attribute inherent in and communicated by one of two or more alternative sequences or arrangements of something that produce specific effects. A signal or character representing data. Something (such as a message, experimental data, or a picture) which justifies change in a construct that represents physical or mental experience or another construct. A quantitative measure of the content of information. The communication or reception of knowledge or intelligence.	Merriam Webster dictionary
International Maritime Organisation IMO	IMO is the UN specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships. IMO's work supports the UN sustainable development goals. IMO develops international safety regulations and recommendations for shipping.	IMO
International Standardisation Organisation ISO	ISO develops and publishes International Standards that support innovation and provide solutions to global challenges. ISO is an independent, non-governmental international organization with a membership of 167 national standards bodies.	ISO

Definition	Explanation	Source
Levels of autonomy, Levels of control, Lloyd´s Register, Lookout		
Degrees of autonomy	Degrees of autonomous functions and human control in systems.	IMO
Levels of autonomy	Levels of autonomous functions and human control in systems.	Lloyd's Register
Levels of control	A number of systems for categorising the level of control applicable to MASS have been developed. Level 0 Crewed, level 1 Operated, level 2 Directed, Level 3 delegated, level 4 monitored and level 5 Autonomous.	EDA SARUMS and Maritime UK, Industry Code MASS
Lloyd´s Register	Lloyd's Register is a global professional services company specialising in engineering and technology for the maritime industry. Lloyd´s Marine and Offshore is a leading provider of classification and compliance services to the marine and offshore industries, supporting design, construct and operate assets to the safety and environmental compliance.	LR
Lookout	Activity carried out by sight and hearing as well as by all available means appropriate for the prevailing circumstances and conditions to make a full appraisal of situation and the risk of collision. A member of the crew stationed on the forecastle, or on the bridge, whose duty is to watch for any dangerous objects or for any other vessels heaving into sight.	Babicz, Wärtsilä encyclopedia of ship technology
	Activity carried out at all times by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.	BV Guidelines for Autonomous Shipping
Maritime Autonomous Surface Ship, Master, Monitor, Monitoring		
Maritime Autonomous Surface Ship MASS	Maritime Autonomous Ship System. This definition of MASS used in the Code encompasses a vessel and all associated on-board, off board and RCC systems. A surface ship that is capable of being operated without a human on-board in charge of that ship and for which the level of control may encompass. Term adopted from IMO.	Maritime UK and IMO scoping exercise
Monitor	To monitor means is to watch, keep track of, or check usually for a special purpose.	Merriam Webster dictionary
Monitoring	Act of periodically checking equipment and environment in order to detect any changes	BV Guidelines for Autonomous Shipping
Navigation, Navigation aids, Navigating and manoeuvring workstation		
Navigation	All tasks relevant for deciding, executing and maintaining the course and speed in relation to waters and traffic.	Babicz, Wärtsilä encyclopedia of ship technology
	The act or practice of navigating or the science of getting ships, aircraft, or spacecraft from place to place especially, the method of determining position, course, and distance travelled. Ship traffic or commerce.	Merriam Webster Dictionary
Navigation aids	Magnetic compass, gyrocompass, radar, echo sounder, rudder angle indicator, propeller revolution counter, rate of turn indicator.	Babicz, Wärtsilä encyclopedia of ship technology
Navigating and manoeuvring workstation	The main workstation on the bridge where speed and course are considered and controlled, preferably conceived for working in the seated position with optimum visibility and integrated presentation of information and operating equipment. It shall be possible from this place to operate the ship safely, in particular when a fast sequence of action is required.	Babicz, Wärtsilä encyclopedia of ship technology

Definition	Explanation	Source
Officer of the watch, OODA, Operation, Operator		
Officer of the watch	The person responsible for safe navigating, operating of the bridge equipment and manoeuvring of the ship.	Babicz, Wärtsilä encyclopedia of ship technology
OODA	OODA loop stands for Observe -> Orient -> Decide -> Act. And as the term loop indicates, the process is continual. The OODA model was developed by John Boyd, a military strategist and applied to fighter jet operations.	Gasaway
Operation	Performance of a practical work or of something involving the practical application of principles or processes	Merriam Webster Dictionary
Operation Management System	The operation management system is the integration platform for operation system sensors, effectors and sub-systems and enables the centralized use of all integrated operation system components.	AEFI OMS product description
Operator	Person in the remote-control centre to provide remotely navigation and maintenance of the ship, its machinery, systems and arrangements essential for propulsion and safe navigation or to provide remotely services for other persons aboard. An entity (e.g. a company) that discharges the responsibilities necessary to maintain the MASS in a seaworthy condition and compliant with all relevant IMO Instruments and national legislation. The operator is also responsible for ensuring that all staff concerned with the control of MASS hold appropriate qualifications as required by IMO instruments and national legislation.	BV Guidelines for Autonomous Shipping Maritime UK
Payload, Plan-Do-Check-Act		
Payload	Additional load for devices, equipment, people, materials, which are not necessary for the direct navigational transit operation of a UMS, but are serving for the mission to be performed.	EDA SARUMS
Plan-Do-Check-Act	Plan-Do-Check-Act (PDCA) cycles are one of the most established cycles among quality control procedures. PDCA is a four-step model for carrying out change. PDCA cycle should be repeated again and again for continuous improvement. The PDCA cycle is considered a project planning tool.	ISO 9001:2015 ASQ www.asq.org
Requirement, Remote-control		
Requirement	Something necessary, indispensable, or unavoidable	Merriam Webster Dictionary
Remote-control	A device or array of devices connected to a machine by mechanical, electrical, pneumatic, hydraulic or other means and by which the machine may be operated remotely from, and not necessarily within sight of the operator. Control of an operation at a point distant from the controlled device, using the transmission of information by telecommunications techniques. A mode of operation of UMS wherein a human Controller, without benefit of video or other sensory feedback, directly controls the actuators of the UMS on a continuous basis, from off the vehicle and via a tethered or radio linked control device using visual line-of-sight cues. In this mode, the UMS takes no initiative and relies on continuous or nearly continuous input from the user. Operational control of some or all ship operations or functions, at a point remote from the ship. Control (as by radio signal) of operation from a point at some distance removed or a device or mechanism for controlling something from a distance.	Babicz, Wärtsilä encyclopedia of ship technology BV Guidelines for Autonomous Shipping EDA SARUMS Maritime UK Merriam Webster Dictionary

Definition	Explanation	Source
Remote-control centre and station, Remote monitoring, Risk, Risk management		
Remote-control centre	Area located on-shore or on another ship (conventional ships included) or on an offshore unit from which the monitoring and control the ship is exercised.	BV Guidelines for Autonomous Shipping
	Set or system of equipment and control units that are needed at the site or sites where safe and effective remote command, control and/or monitoring of the MASS, or several MASS, is conducted. A site off the ship from which control of an autonomous ship can be executed. The RCC may be located either ashore or afloat and may exercise varying degrees of control as defined under “Levels of Control”. An RCC may consist of more than one Control Station or Room.	Maritime UK
Remote-control station	The remote location where the designated operator with responsibility over the autonomous or remote-control function is located.	American Bureau of Shipping
	A location fitted with means of remote-control and monitoring.	Babicz, Wärtsilä encyclopedia of ship technology
	Control station located in a remote-control centre.	BV Guidelines for Autonomous Shipping
Remote-control systems	Remote-control systems comprise all equipment necessary to operate units from a control position where the operator cannot directly observe the effect of his actions.	BV rules for classification of high speed craft
Remote monitoring	Monitoring some or all ship operations or functions at a point remote from the ship.	Maritime UK
Risk	The product of the frequency with which an event is anticipated to occur and the consequence of the event’s outcome.	American Bureau of Shipping
	Concept quantifying a hazard, consisting in a combination of probability or frequency and consequence of the related hazard.	BV Guidelines for Autonomous Shipping
	Effect of uncertainty on objectives. An effect is a deviation from the expected, positive and/or negative.	ISO 31000:2011
Risk management	Coordinated activities to direct and control an organization with regard to risk.	ISO 31000:2011
Sense and Avoid, Situation Awareness, Sensor, System, System of systems		
Sense and Avoid	The capability of a UV to remain well clear from and avoid collisions with other waterborne traffic. SA provides the functions of self-separation and collision avoidance to fulfil any regulatory requirement.	EDA SARUMS
Situation Awareness	The perception of 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”	Designing for SA
Sensor	A device that responds to biological, chemical, or physical stimulus (such as heat, light, sound, pressure, magnetism, motion, and gas detection) and provides a measured response of the observed stimulus (ISO/IEC/IEEE 21451-7).	BV Guidelines for Autonomous Shipping
System	A system is the combination of elements that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose.	NASA System Engineering Handbook 2020
System of Systems	The large-scale integration of many independent task-oriented systems to create a larger, more complex system which offers more functionality and performance than simply the sum of the constituent systems.	American Bureau of Shipping

Definition	Explanation	Source
Task analysis		
Task analysis	Task analysis is a way of systematically describing human interaction with a system to understand how to match the demands of the system to human capabilities.	Designing for SA
Uncrewed, Unmanned		
Uncrewed	A ship with no crew on-board. Crew does not include passengers or special personnel.	Maritime UK
Unmanned	Not carrying, staffed, or performed by people, not manned	Merriam Webster Dictionary
Unmanned Maritime System	Includes all systems, associated components and subsystems needed to operate these systems with control system, vehicle, logistics and interacting personnel.	EDA SARUMS
Unmanned Maritime Vehicle	Remotely controlled or autonomous craft, vessel or ship with the ability to function without a bridge crew on-board.	EDA SARUMS
Unmanned ship	A ship having no crew to operate ship systems. An unmanned ship may be remotely controlled or supervised by operators or with full automation. It may have passengers, special personnel according to SPS Code MSC.266 (84) or temporarily technical personnel aboard an unmanned ship.	BV Guidelines for Autonomous Shipping
Unmanned Surface Vehicle	A vehicle which operates autonomously or is controlled and commanded remotely.	EDA SARUMS
Unmanned vehicle	A powered vehicle that does not carry a human operator and can be operated autonomously or remotely, be expendable or recoverable and can carry lethal or non-lethal payloads.	EDA SARUMS
Watch, Watch alarm, Watch alarm system		
Watch	A time period, usually of four hours, e.g. 12-4, 4-8, 8-12, which operates round the clock. It is the working period for one or more officers and crew in the navigation and engineering departments.	Babicz, Wärtsilä encyclopedia of ship technology
Watch alarm	An alarm that is transferred from the bridge to the master and the backup navigator in the event deficiency (absence, lack of alertness, no response to another alarm/warning, etc.), of any officer on watch. See also Vigilance system.	Babicz, Wärtsilä encyclopedia of ship technology
Watch alarm system	The watch alarm system urges the officer on watch at a predetermined time to acknowledge his watch-keeping awareness.	Babicz, Wärtsilä encyclopedia of ship technology

Table 10: Definitions and explanations.