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Tore Relling

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The Vessel Traffic Service's contribution to safe coexistence between autonomous and conventional vessels

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Aalesund, December 2020

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Department of Maritime Studies

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A systems perspective on maritime autonomy:

The Vessel Traffic Service's contribution to safe coexistence between autonomous and conventional vessels

Submitted as part of the PhD Programme in Nautical Operations: Joint Degree between Norwegian University of Science and Technology, the Western Norway University of Applied Sciences, the University of South-Eastern Norway, and UiT the Arctic University of Norway

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Co-supervisor: Professor Margareta Lützhöft, Western Norway University of Applied Sciences

Co-supervisor: Associate Professor Dr Runar Ostnes, Norwegian University of Science and Technology

Abstract

The technology development is a cornerstone of continuously improving the society. Automation has increased efficiency, and during the last decade, digitalisation has been another game changer that has opened for technology taking an even larger role in our society. Automation and digitalisation has paved the way for autonomy being the next innovation that can change the transport sectors significantly. However, despite some years with optimism, no commercial maritime autonomous concepts are implemented.

My motivation for the study is that the development of maritime autonomy seems to be challenged by a one-sided technology focus and ignoring humans. Such technology focus, forces the development to be an attempt to make machines as humans, and if technology fails, the autonomous concept should be saved by a human operator. Hence, relying on the humans being idle until the moment they are needed, and then act reliable and swift, much like a machine would do. Making machines as humans, and humans as machines, is a difficult task, and consequently I suggest a different approach to maritime autonomy.

In my study, I suggest using a systems perspective on maritime autonomy where the focus is shifted from the autonomous vessel in isolation, to a systems perspective considering the interaction between the autonomous vessel, conventional vessel, and the Vessel Traffic Services (VTS), while emphasising the human role. My system of interest is the VTS, and I focus on Norwegian waters and the Norwegian Coastal Administration (NCA), which is responsible for the Norwegian VTS'

The theoretical frame of reference follows my motivation of taking a systems perspective that considers system performance as well as the human role. As such, the theoretical frame of reference is both systems theory and human factors theory. The theories overlap on the term resilience and the common objective of maintaining a stable performance in a shifting environment. Safe coexistence between vessels of any kind, is considered such stable performance, and is central for my study.

The philosophical foundation has pointed the research in a different direction than first anticipated. Safe coexistence is an ontologically subjective claim that can be explained by epistemological objective or subjective claims. My background from aviation led me in the direction of searching for objective claims for safe coexistence. However, this was demanding due to little coherence between the available objective measures and the subjective meaning of safety that was expressed by the participants in the study. Consequently, the research was shifted to look for epistemological subjective claims for safe coexistence. Corollary, the causation in the study concerns how to intervene on the role of the VTS to allow for safe coexistence in a future maritime traffic system with conventional and autonomous vessels.

Based on the theoretical frame of reference and the choices of philosophical stances, the requirement for my methodology was to be supported by a known design research methodology, allow for interaction and participation, and iterate between parts and the whole. Consequently, I combined the Design Research Methodology (DRM) with a complementary mindset of systems engineering and human-centred design.

In the first stage of the research, I clarify the research area by discussing the human role in the future maritime system. The study highlights that the ambiguity in the term autonomy creates a challenge for the development and a set of parameters to describe autonomy is presented. The human role in maritime autonomy is discussed and emphasises that humans will strengthen the system and will remain responsible.

The second stage of the research provides a deeper understanding of the existing role of the VTS. Both a systems approach, of the VTS as a system, and a focus on the humans, the VTS operators, are applied. The systems perspective describes the VTS as a control system in a Maritime Traffic System. Subsequently, the law of requisite variety from cybernetics shows that a VTS needs to have a variety in response equal to, or larger, than the variety in demands by the environment. Focusing on the humans, the research shows that this variety is created by the VTS operators and to explore this performance variety, a cognitive task analysis unpacks how VTS operators cope with complexity.

The third stage of the study suggests a socio-technical systems approach to design a future VTS. A democratic approach is recommended, where personnel with different organisational affiliation and expertise provide input to the change. To identify and evaluate changes, internal and external effects to the VTS are considered. The internal effects are identified by a levelled socio-technical approach, while the external effects are found by applying the architectural design principles for system-of-systems.

The final stage of the study applies a user-involved design process, where personnel from the NCA provide input on how to apply traffic organisation and traffic regulation to facilitate for a safe coexistence between autonomous and conventional vessels. The most prominent result is that the VTS needs to change its role from solving problems ad-hoc to taking a tactical responsibility. Some of the identified traffic organisation and regulation measures for the VTS are to some extent present today, while others are new and need to be implemented. The user-involved process, including a prototype of an autonomous vessel in a 2025-scenario, indicates that even if the changes lead to additional responsibilities for the VTS, the measures are considered as feasible and relatively easy to implement.

Acknowledgements

The voyage from starting the PhD to the completion of the thesis has been rewarding and challenging. The navigation on the voyage has from time to time been difficult, partly because of using the wrong map and partly because of my navigational skills. However, as I am close to my destination I need to acknowledge the people who have helped me in determining the position and to find the right course.

First, I would say thanks to my supervisors. The three of you have guided me and asked the difficult questions at the right time and brought important perspectives to my work. Professor Hans Petter Hildre emphasising design and methodology. Dr Runar Ostnes highlighting the importance of consistency and structure of my work. Professor Margareta Lützhöft for all the effort you have put in on everything from grammar to opening the door to social science. During our numerous skype-calls you have patiently helped me to sort my ideas and assisted Kea to navigate in the right direction. I am really grateful for all of your time.

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I would also like to acknowledge the Norwegian Coastal Administration for the openness, participation in the data collection, and interest in my research. Thanks to Trond Ski who has provided information, coordinated my field studies, and arranged for me to present and get feedback in national and international forums.

Thanks to Odd Sveinung for motivating me to apply for the study, and for all the help, discussions, and input during the process.

Last, but not least, thanks to my family. I have several times referred to this study as my mid-life crisis and I think you all would agree that it would have been easier if I just bought a motor cycle. To Elias and Hedda, thanks for being responsible, helpful, and caring. I am proud of you. Finally, thanks to Wenche, for your support, for taking care of everything I forget, for your energy, but most of all for being you.

List of Publications

Paper 1: Relling, Lützhöft, Ostnes and Hildre (2018). “A Human Perspective on Maritime Autonomy.” In Augmented Cognition: Users and Contexts, edited by Dylan D Schmorrow and Cali M Fidopiastis, 350–62. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-91467-1_27

Paper 2: Relling, Lützhöft, Hildre and Ostnes (2019). “How vessel traffic service operators cope with complexity – only human performance absorbs human performance”, Theoretical Issues in Ergonomics Science, DOI: 10.1080/1463922X.2019.1682711

Paper 3: Relling, Praetorius and Hareide (2019). “A Socio-technical Perspective on the future Vessel Traffic Services”, Necesse Vol 4, Issue 1, 112-129. DOI: 10.21339/2464-353x.4.1.1

Paper 4: Relling, Lützhöft, Ostnes and Hildre (In review). ”It is not difficult, we could do it tomorrow: The Vessel Traffic Services contribution to safe coexistence between automated and conventional vessels”. Maritime Policy & Management.

Content

1 Introduction

Technology has been, and still is, important to improve society. Steam engines, combustion engines and electricity have been cornerstones for a continuous societal development. High risk duties have been lifted from human shoulders by technological inventions and new business models have emerged. Over the last forty years, automation has taken over more of the traditional human tasks and made the human role more distant from the actual operation. In the last decade, digitalisation has allowed for more integration of information, interconnections of components, and has opened for technology taking an even bigger role in our society (Baden-Fuller and Haefliger 2013; Pereira and Romero 2017). In the transport segments, digitalisation has led to an increased interest in *autonomy,* and developing self-driving capabilities is high on the research and development agenda.

However, technology developments rarely deliver the promised value neither immediately nor completely. Gartner's *'Hype Cycle'* is a common pattern followed by new technologies or innovations. This describes the path towards productivity in five levels from the time when innovation is triggered to the time innovation becomes productive as shown in Figure 1 (Linden and Fenn 2003). Some innovations make it through the cycle in short time, others take longer time, and some innovations do not make it at all and become extinct.

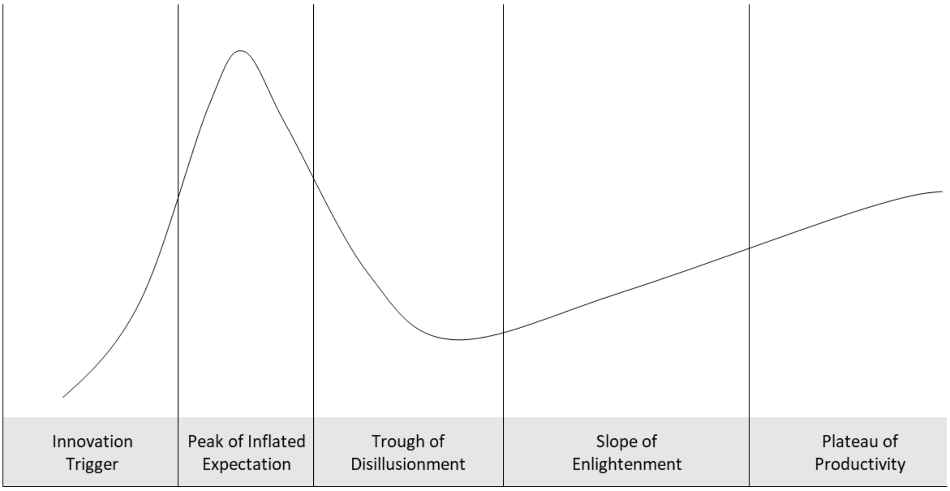

Figure 1: Gartner's Hype Cycle presents a common pattern of new technologies from triggered by innovation to productivity (Linden and Fenn 2003)

The hype cycle indicates that the expectation of most technologies progress rapidly after an innovation trigger. At the peak of inflated expectations, the expectations rise above the factual capabilities which leads to the stage of disillusionment where impatience for results replaces the excitement about the technology. When the obstacles in the challenges of the three first phases in the hype cycle have been overcome, in combination with an increased understanding about how to implement technology, the slope of enlightenment starts. Finally, if demonstrated useful, the technology enters the plateau of productivity (Linden and Fenn 2003).

In the maritime industry, autonomy has promised to increase safety, reduce cost, and lower emissions (SINTEF 2017). However, despite being top priority for many maritime developers the last five years (Rolls-Royce 2016) and in the International Maritime Organization since 2017 (IMO 2018), no autonomous concepts of merchant shipping size has yet become operational. After the initial optimism related to the autonomy development, sceptics are questioning the actual demand of such capacity and calling autonomy a hype (Hand 2017). The overall question for autonomy, convergent for all transport sectors, seems to be if and how technology can replace humans. A major challenge to this is the ambiguity of responsibility and technical capabilities that has not been resolved in a way that moves maritime autonomy towards reality.

Authorities have been explicit that “someone” must be responsible for autonomous vessel, referring to humans still being responsible for the operations (NMA 2018). Consequently, the preliminary discussions of autonomy have mainly been about developing smart ships that perform as human navigators, while being backed up from a shore centre responsible for, and constantly ready to take over, the operation. The challenge of allocating responsibility to the shore centre is similar to what Bainbridge (1983) refers to as the “ironies of automation”. The irony Bainbridge refers to, is giving responsibility to technology since it is seen as superior to humans, while expecting humans to take over the responsibility when technology fails. Consequently, the humans are out of the loop most of the time, but still being responsible to get in the loop with a swift response whenever needed.

The technical capabilities of digitalisation are the most significant drivers initiating the autonomy discussion. Even though the idea of autonomy was initiated by digitalisation, I have been puzzled by the one-sided technology focus in the developing the concept of autonomy. The discussions of future autonomous concepts follows the *principle of equivalence*, where the goal of the principle is that the new concept is as safe or safer than existing designs (International Maritime Organization 1974, 2013; Ramos et al. 2019). Such discussions could easily end up comparing technological and human capabilities to see if technology could replace humans, e.g. comparing sensors and the human eye. It is unquestionable that we will have sensors more capable than the human eye, but is autonomy only a question of replacing humans with technology, and further, should all questions be answered by technology? The consequence of answering challenges with technology, reduces the question of safety to a question of reliability; if the technical component is more reliable than human performance, it is considered safe.

In my perspective, the current development of autonomy is an attempt to make machines as humans, and humans as machines. However, in terms of the hype cycle, the development has currently failed to take maritime autonomy from the initial phase triggered by digitalisation to the productivity phase, which indicates a development that may be going in the wrong direction.

In this thesis, I take a broader approach to digitalisation and argue that digitalisation is more than the technology itself. To avoid a reductionist approach to developing maritime autonomy with a one-sided technological focus, I suggest a *systems perspective* of maritime autonomy where the focus is shifted from the autonomous vessel to the interaction between autonomous vessels, conventional vessels, and Vessel Traffic Services (VTS). To allow for a safe and efficient interaction, I highlight the importance of understanding and designing for the humans.

The systems perspective of the study is to consider a wholeness of both system performance and the human role, and as such, the theoretical frame of references for the study is both systems theory and human factors theory. Despite having some differences, the theories have several similarities. These similarities are used to support the systems perspective when introducing autonomy in the maritime industry and the study applies a methodology emphasizing the complementary perspectives of systems engineering and human-centred design.

The VTS is the system of interest in this study and is considered to be a control system that affects the interaction between vessels. The study focuses on Norwegian waters, where the responsible organisation for the VTS is the Norwegian Coastal Administration (NCA). The VTS is one of the most important measures for the Ministry of Transportation to ensure their responsibility of maritime infrastructure and services for safe maritime traffic (Ministry of Transportation 2019). My focus on the VTS in the autonomy development is suggested to contrast the focus on the capacity of the individual autonomous vessel in isolation. Consequently, it indicates that the responsibility for developing autonomous solutions is a governmental responsibility, and to identify how the VTS could support a future maritime traffic system is an important part of such responsibility.

1.1 Objectives and research questions

The objective for the study is to present a holistic approach to a digitalisation-driven development. The study explores the development of autonomy in maritime industry and presents an alternative perspective from the autonomous vessel in isolation to a systems perspective to explore if the Vessel Traffic Services (VTS) can facilitate for safe coexistence between autonomous and conventional vessels. The main issue for the study is:

How could a systems perspective enable for autonomy in the maritime industry?

To answer the main research question, four sub-research questions are defined:

Research question 1: What is the human role in the future maritime system?

> Autonomy is expected to cause major changes, where changes to the human role is one of the most pronounced. The research question discusses:
>
> > 1 a) What is autonomy?
> >
> > 1 b) How could a systemic human-technology approach in maritime autonomy be adopted?

Research question 2: What is the Vessel Traffic Services' role in the maritime system?

> The VTS is an important safety measure in today's maritime system. To understand the role of the VTS, and in particular the role of the VTS operators, the following are discussed:
>
> > 2 a) How do the VTS contribute to the maritime traffic system?
> >
> > 2 b) How do VTS operators use expert knowledge and strategies in the interaction with vessels?

Research question 3: Which approach can support design of the future VTS?

> The future VTS can experience new challenges due to autonomy. To identify the challenges, the following is discussed:
>
> 3 a) How can a socio-technical systems approach focusing on a democratic process, and systemic evaluation of internal and external consequences, be used in the early design phase of the future VTS?

Research question 4: Can the Vessel Traffic Services facilitate safe coexistence in the future maritime system?

> The challenges caused by autonomy could be met by taking a systems perspective. This indicates that changes could be seen across various component systems, and as such, changes to the VTS might be beneficial to the coexistence between conventional and autonomous vessels. The research question discusses:
>
> > 4 a) Can the future VTS apply traffic organisation and traffic regulation measures to facilitate for safe coexistence between conventional and autonomous vessels?

1.2 Limitations

The thesis discusses the development towards a future maritime system where autonomy is realised. The development of autonomy is still uncertain and could take different directions. A rapid development of technology to create an isomorphism between human and technology behaviour is not considered likely to happen within the next five years, and consequently is not discussed in this thesis. Additionally, the thesis focuses mainly on the VTS, although in a systems perspective more interactions between all component systems in the maritime system should be assessed, and ideally following an iterative process. The time available in the study has not allowed for exploring the challenge from all aspects, and consequently is a limitation for the project. Finally, the project discusses only the navigation function, and other maritime functions such as engineering functions, cargo handling, mooring, special operations, or similar, are not covered.

1.3 About the thesis

Chapter 1 introduces the research problem and outlines the research questions and limitations. Chapter 2 presents the regulatory background for maritime autonomy, maritime traffic management, a brief description of the VTS, and on-going research relevant to this study. Chapter 3 introduces the theoretical frame of reference for the project, chapter 4 delineates the philosophical foundation, and chapter 5 describes the methodology. Chapter 6 renders the results and discussions in the for the study. The chapter has four sub-chapters, one for each of the research questions described in 1.1. The contribution of the thesis is discussed in chapter 7. Suggestions for future work is found in chapter 8, while finally, the conclusions are presented in chapter 9.

The thesis could be written in the first person or the third person. I have used both first and third person throughout the thesis. Where I want to underline my presence in the research and how my values both affect the research topic and the actual research, I use the first person. When presenting objective truths, such as the structure of the thesis or referring to other work, I use the third person.

2 Background

The shipping industry is responsible for transporting about 80 per cent of the global trade and, hence, is crucial for society. In the transport segment, more than 95,000 ships moved 11 billion tons of goods in 2018 (UNCTAD 2018). The number of existing ships shows that even though autonomy could be considered as disruptive for the maritime industry, conventional vessels will be in absolute majority for the foreseeable future. Therefore, existing international and national regulations are relevant when aiming for a safe coexistence between autonomous and conventional vessels. Specifically, it is relevant to highlight regulations which are closely linked to human roles and responsibilities such as parts of the COLREGs that depend on human judgement. This strong connection between humans and regulations can be a barrier that keeps autonomy in the trough of disillusionment in the hype cycle, as discussed in the introduction and visualised in Figure 1. Consequently, it is relevant to describe ongoing initiatives to identify challenges in existing regulations and to adapt these regulations for maritime autonomy.

In the background chapter, the status of development of maritime autonomy is briefly presented, followed by relevant regulations for maritime traffic management. Finally, a general presentation of the aims and objectives for Vessel Traffic Services is given, followed by a delineation of the Norwegian VTS.

2.1 Maritime autonomy

Maritime autonomy is currently in the making, and gains interest among operators, equipment and vessel designers, class societies and in IMO. Even though no maritime autonomous concepts of merchant shipping size are currently in operation, several initiatives contribute to drive the development forward. This thesis does not give a complete overview of all initiatives but will describe some relevant initiatives for this thesis related to regulations, and research and concept development.

2.1.1 Regulations

International Maritime Organization (IMO). The IMO Strategic Plan defines a key strategy to "integrate new and advancing technologies in the regulatory framework". As part of the strategy, IMO has initiated a regulatory scoping exercise for autonomy. Maritime Autonomous Surface Ships (MASS) have been on the agenda in the Maritime Safety Committee (MSC) in IMO since 2017 and in 2019, the MSC approved the interim guidelines for MASS trials. In addition to the MSC, the Legal Committee (LEG), the Marine Environment Protection Committee (MEPC) and the Facilitation Committee (FAL) are all contributing to the regulatory scoping exercise, planned to be completed in 2020 (IMO n.d.).

Danish Maritime Authority (DMA). The DMA has identified, systematised, and presented recommendations for handling regulatory barriers to the development of autonomous ships. The analysis explores regulatory barriers to commercial shipping and addresses jurisdictional issues, navigation and regulations for preventing collisions at sea, crew and seafarers of the future, protection of the marine environment, construction requirements and technical conditions of ships, liability, compensation and insurance issues, cybersecurity and anti-terror safeguards (Danish Maritime Authority 2017). 37 regulatory barriers were identified, where 27 of them are to some degree related to the human role or responsibility. The DMA has also funded a pre-investigation into the potential of autonomous ships, defining maritime autonomy and discussing political and competitive considerations (Technical University of Denmark 2017).

Norwegian Coastal Administration (NCA). The NCA has suggested changes to the pilot regulations to remove some regulatory obstacles for autonomous operations. The main change is to permit autonomous operations within a defined area for operations if it is safe for the autonomous vessel and other traffic in the area (Norwegian Coastal Administration 2018). The NCA has currently defined five test areas for autonomous operations (Norweigan Coastal Administration 2017).

Class Societies. The International Association of Classification Societies (IACS) has acknowledged that autonomy creates a need to develop new technical requirements. The IACS contributes to the technical discussions in the IMO regulatory exercise by reviewing their Resolutions and Recommendation to highlight hindrances for autonomy (IACS 2019). Several of the class societies have published guidelines or codes for autonomy. DNV GL has Guidelines for Autonomous and Remotely operated ships (DNV-GL 2018), Lloyds Register has Unmanned Marine Systems Code (Lloyds Register 2017), Bureau Veritas has Guidelines for Autonomous Shipping (Bureau Veritas 2017), and ClassNK has Guidelines for Concept Design of Automated Operation/Autonomous Operation of ships (ClassNK 2020)

2.1.2 Research and concept development

The following section briefly presents on-going or planned initiatives for developing autonomous concepts, and further autonomy networks and research.

Autonomous concepts. Some concepts are developed to support rather than replacing the navigator. The shipping company NYK has performed a trial of a manned autonomous ship operations using advanced technologies and support from shore to support the ship operations (NYK 2019). Wärtsilä has tested autonomous ferry crossings with two passenger ferries. One ferry in Norway and one in Finland have been able to perform a test dock-to-dock voyage without human intervention (Wärtsilä 2018).

Kongsberg develops an autonomous feeder for Yara to sail between three ports in South Norway. The vessel will have a capacity of 120 TEU (Twenty-foot Equivalent Units), battery powered and planned delivery in 2020 and autonomous operations in 2022[1]. Three shore centres are planned to handle the operations (Kongsberg 2020). The grocery distributor ASKO plans to replace 150 daily truck trips with two battery driven vessel crossing the Oslo Fjord (Massterly n.d.)

Several projects to develop small passenger boats aim to develop small passenger boats to sail short-distance crossings (Lofoten Matpark AS 2018; NTNU 2019). Other projects explore small subsea and surface vessels that would do “dull, dirty or dangerous” tasks. Most of these vessels are for oceanographic or military use (National Ocenography Centre 2018; Hareide et al. 2018).

Networks. Several networks are established to promote autonomy. The Institute of Marine Engineering, Science and Technology (IMarEST) has established a special interest groups for Maritime Autonomous Surface Ships, responsible for a programme for early stage research and technologies. The Norwegian Forum for Autonomous Ships (NFAS) is an interest group for Norwegian organisations to strengthen cooperation, contributing to development of Norwegian strategies and developments, and to strengthen the international contacts and influence on autonomous shipping. The One Sea is an initiative to develop the maritime autonomous ecosystem and aims to set industrial standards to advance towards implementation of autonomy in 2025.

Research. The research on maritime autonomy is as extensive as the term itself and includes a large variety of topics such as technical capabilities, legal matters, the human role, or organisational aspects. While some of the research is carried by individual organisation, a substantial part of research projects is a part of joint initiatives between the industry, academia and governmental or inter-governmental cooperation, such as the EU Horizon 2020 initiative ‘Autoship’ (Autoship Consortium, n.d.), the International Conference for Maritime Autonomous Surface Ships (ICMASS), the NTNU Centre for autonomous marine operations and systems (AMOS) (NTNU, n.d.) or the Advanced Autonomous Waterborne Applications Initiative (AAWA) (Rolls-Royce 2016).

This thesis will not provide a review of all on-going research projects, but two research projects are mentioned. One is the MUNIN-project, which is frequently used as a reference in on-going research and is important due to the broad feasibility assessment of an autonomous concept. The other is

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[1] Some media reports that the development is on hold due to the Covid -19 and changed global outlook (The Maritime Executive, n.d.)

HUMANE, an on-going research project that similar to MUNIN takes a broad approach to autonomy, while keeping humans in the centre of the design.

Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) is an extensive research project to describe the development of a concept of an autonomous ship. MUNIN defines systems for lookout duties, a navigation system, engine monitor and control system and shore control centre. The project developed a technical concept for an unmanned vessel and assessed its technical, economical, and legal feasibility. By exploring feasibility from these different aspects, MUNIN was able to discuss a concept that is economical beneficial, while also highlighting future research.

MUNIN underlines that the results are associated with a high level of uncertainty but appears to show that autonomous ships have a potential to increase the profitability for ship owners. The base scenario for the project, an autonomous bulk carrier, shows a reduced cost of 7 million USD over a 25-year period compared to a conventional vessel. The legal framework is considered possible to adapt to autonomous concepts, as long as the ship can operate safely, even though many issues remain to be solved. One of the issues the project states to remain to be solved is the liability, and particularly if the existing ship master duties should be divided between shore control operators and masters or given to a single entity in the shore control room (MUNIN 2015).

The Human Maritime Autonomy Enable (HUMANE) is an on-going research project takes a human-centred perspective on maritime autonomy. The project started in 2018 and will conclude in 2021. HUMANE applies the human-centred perspective to evaluate the implications of autonomy and propose enabling approaches to necessary changes in the process of developing it. Areas for the research is organisation, education, training, assurance, policy, regulation, law and how the methods can support stakeholders in preparing for the new disruptive technology (Western Norway University of Applied Sciences n.d.)

2.2 Maritime Traffic Management

Maritime Traffic Management (MTM) is used as a term for measures for a safe and efficient traffic flow. Other terms as Sea Traffic Management (STM) or Vessel Traffic Management (VTM) are also used as synonyms for MTM. IMO uses, but not defining, the term MTM. In the thesis MTM is used as a collective term for regulations, rules and services used for safe and efficient traffic flow. The most predominant MTM measures for this thesis are the United Nations Convention on the Law of the Sea (UNCLOS), Convention on the International Regulations for Preventing Collisions at Sea (COLREG), International Maritime Organization's Safety of Life at Sea (SOLAS) and the Vessel Traffic Services (VTS). IMO has initiated a regulatory scoping exercise for maritime autonomy, where SOLAS, COLREG, Load Lines, training, search and rescue, tonnage measurement and special trade passenger ship instruments, will be covered (International Maritime Organization n.d.). Since the scoping exercise for regulations is still underway, this will not be discussed further. The relevant aspects to the thesis of the existing UNCLOS, COLREG and SOLAS are referred to in the following section.

2.2.1 United Nations Convention on the Law of the Sea (UNCLOS)

The United Nations Convention on the Law of the Sea (UNCLOS) is a treaty defining rights and regulations of the movement on, and the use of, the sea (United Nations 1982). UNCLOS defines both duties for coastal states on publication of danger of navigation (article 24) and the rights of protecting the coastal states territorial waters (article 25). The treaty describes the right to adopt international laws and regulations for safe navigation (article 21), establish sea lanes and traffic separation schemes in territorial waters (article 22), in international waters (article 41), and in archipelagic waters (article 53). UNCLOS states that a master and officer with appropriate qualifications must be in charge on the vessel (article 94). The coastal states are given the right to define conditions for vessels under their national flags (article 91), and all vessel under a coastal states flag can sail vessels on the high seas (article 90). UNCLOS only mention the International Maritime Organization (IMO) once, however, the term ‘competent international organization’ is used, and this points to IMO as they are a specialised agency with a global mandate from the UN (IALA 2016b).

2.2.2 Convention on the International Regulations for Preventing Collisions at Sea (COLREG),

The International Maritime Organization is responsible for the Convention on the International Regulations for Preventing Collisions at Sea (COLREG). COLREG concerns rules for navigation at sea to prevent vessels from colliding. The current convention was adopted in 1972 and did entry into force in 1977 (IMO 1977) . An autonomous vessel must adhere to all rules in COLREG, however, Porathe (2019) claims that some rules are more challenging than others. He highlights the responsibility (rule 2), conduct of vessels in head-on and crossing situations and actions of give-way and stand-on vessels (rule 15-17), restricted visibility (rule 19) as challenging. The Danish Maritime Authorities analysis of regulatory requirements (2017) underlined the fundamental principle in COLREG is ships being controlled by human beings. They claimed to deduce the principle from precedence on ordinary seamanship (rule 2), look-out (rule 5), safe speed (rule 6), precautions to avoid collisions (rule 8).

2.2.3 International Convention for the Safety of Life at Sea (SOLAS)

The International Maritime Organization’s International Convention for the Safety of Life at Sea (SOLAS) has been updated several times, often to include lessons learned from maritime accidents. The current version is the 1974 convention with several amendments. The main objective for the SOLAS convention is giving minimum standards for construction, equipment and operation of ships (International Maritime Organization 1974). Vessel traffic can be regulated by passive means such as routing systems, or active through VTS, or both. SOLAS chapter V, regulation 10, covers ships’ routeing systems and regulation 12 considers Vessel Traffic Services. They define that governments should follow IMO guidelines for planning and implementation of VTS and routeing systems.

For construction of ships, SOLAS requires the ships to be designed, constructed, and maintained by the requirements of a class society. However, a Flag State’s administration can approve ships with novel features as long as they are sailing in domestic waters (DNV-GL 2018).

Requirements for equipment are linked to conventional shipping, and DMA (2017) identifies requirements such as electronic lookout, design and construction of electronic bridges that need to be in place to allow for autonomy.

For operations, SOLAS has defined requirements both for the governments and for operations on the individual ship. Convergent to UNCLOS, SOLAS states the governmental responsibility is to make any dangers for navigation known, including establishing aids to navigation. Governments are also responsible for initiation of establishing and proposing of Vessel Traffic Services and ship’s routeing system, while IMO develops guidelines, criteria, and regulations. Operational requirements for vessels in SOLAS consider manning, bridge design and equipment and maintenance related to navigation.

2.3 Vessel Traffic Services

Vessel Traffic Services were initiated by the combined use of shore-based radars and communication to improve safety and efficiency. The first to implement the combined use for a port control station, was in Douglas, Isle of Man, in 1948. The first international harmonisation of regulations for such services came in 1968 by the Inter-Governmental Maritime Consultative Organization (IMCO). The recommendation stated that the governments should consider setting up services for ports and approaches. In 1985, IMO issued Guidelines for Vessel Traffic Services for planning and operational procedures. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and the International Maritime Pilots’ Association (IMPA) performed a study on the requirements for VTS. This study was an input to the updated 1997 IMO resolution Guidelines for Vessel Traffic Services A.857(20), which is the current internationally recognised guideline for VTS. (IALA 2016b).

IMO resolution A.857(20) (1997, 3) defines Vessel Traffic Services as:

> *Vessel traffic service (VTS) - a service implemented by a Competent Authority, designed to improve the safety and efficiency of vessel traffic and to protect the environment. The service should have the capability to interact with the traffic and to respond to traffic situations developing in the VTS area.*

The resolution defines the Competent authority to be the authority made responsible by the government for safety and efficiency of the vessel traffic and protection of environment. Further, the purpose of VTS is to improve safety and efficiency of navigation. The resolution makes a distinction between a Port or Harbour VTS and a Coastal VTS. Where a Port or Harbour VTS is concerned with traffic to and from ports, the Coastal VTS concerns traffic passing through an area. Three types of VTS services are described:

> **Information Service (INS).** A service by broadcasting information at fixed times or when considered necessary by the VTS or requested by a vessel. The service could include position reports, information about other traffic, waterway conditions, weather, hazards, or other essential information for navigation.
>
> **Navigational Assistance Service (NAS).** A service provided in difficult navigational or meteorological conditions or if vessels experience defects or deficiencies. The service could be requested by the individual vessel or given if the VTS consider it necessary.
>
> **Traffic Organisation Service (TOS).** A service that includes the operational management and planning of future traffic movements to prevent congestion and dangerous situations. TOS includes traffic clearances and VTS sailing plans for vessels such as allocating space, establishing mandatory reporting of movements, routing, or speed.

IMO A.857(20) is specifies that the role of the VTS is to provide result-oriented instructions and the VTS should not infer on the assessments such as course to be steered or engine manoeuvres to be executed. This to avoid the VTS taking over the master's responsibility for safe navigation, and a VTS sailing plan cannot supersede the master's decision on navigation and manoeuvring of the vessel.

IALA is a non-governmental organisation (NGO) who has consultative status with IMO. The IALA established a VTS committee in 1980 and aims to contribute to safe, economic, and efficient maritime traffic by harmonising navigational aids and other means. The IALA has four committees, one of which is the VTS committee is one, working with VTS operations, training, and technology. The documentation of the IALA work is published in a documentation hierarchy with standards/recommendations, guidelines, and manuals. Standards and recommendations is the highest documentation level and provides direction to plan, operate, and manage for uniform procedures and processes for the services. Guidelines give information on a specific subject, while manuals provide the overview of a large subject area (IALA 2016b).

2.3.1 Norwegian Vessel Traffic Services

UNCLOS defines rights and duties for the coastal states, and to manage this is a governmental responsibility. Broadly, the governmental responsibility is two-fold: First, it considers the *flag state responsibility* where a nation state has the jurisdiction and control of the vessel's administrative, technical, and social matters (Mansell 2009). Second, it covers the *responsibility for the territorial waters*, where nation states may adopt laws and regulation related to safety of navigation and regulation of maritime traffic (United Nations 1982).

When autonomous vessels are being introduced, the Norwegian government needs to consider the flag state requirements and the responsibility for the territorial waters, just as for conventional vessels. The flag state requirements are to a lesser degree discussed in this study. The Norwegian Ministry of Transportation (MoT) is responsible for maritime infrastructure and services for safe maritime traffic in Norwegian waters. They use two areas of responsibility; one is the infrastructure such as aids to navigation, the other is the VTS and message services. The Norwegian Coastal Administration (NCA) is the executive agency, hence is the competent authority for the VTS. MoT manage their responsibility through an annual award letter with assignments to the NCA. This describes that the NCA services should contribute to the main goals of increased efficiency and safety, reduce emissions, and for oil-spill preparedness (Ministry of Transportation 2020). The NCA operates five VTS': Horten, Brevik, Kvitsøy and Fedje are responsible for areas in Norwegian territorial waters, while Vardø VTS is responsible for traffic following the ship routing system in international waters. Each VTS is manned with two VTS operators 24/7. The movement of traffic in the VTS areas is regulated by Regulations for Vessel Traffic Services (Ministry of Transportation 2015).

2.3.2 Previous studies on Vessel Traffic Services

Previous studies on VTS show that different work practice, lack of standardized communication, mistrust between the VTSO and pilot/navigator, and lack of time for planning is present at VTS' in other Nordic countries.

Different work practices. Nuutinen, Savioja and Sonninen (2007) studied how Finnish VTS' have developed to identify a recommended future development strategy. The main finding is that each of the six VTS centres in Finland is unique. The level of service is different from centre to centre, from operator to operator and even that services is conducted differently by the same operator from time to time. Mansson (2017) studied teamwork in the maritime traffic system in Australia, and found indication of maritime professionals adapting their performance to get the job done. He states that even if such adaption is necessary, it reduces the participants' ability to establish common ground. Praetorius (2014) elaborates on the importance of understanding how performance varies in VTS as a socio-technical systems and the importance of understanding the consequences of such performance variability. She argues that the limited legal support in clearly defining the role of the VTS has a negative effect on safety and efficiency.

Communication. In a study exploring the concept of pilotage of vessels from a shore based location, a focus group on the 'shore perspective' covered the topics: *Contact ship-VTS, Safety, Traffic flow* and *General* (Lützhöft, Dahlman, and Prison 2008). Under the topic 'contact ship-VTS' the participants from a Swedish vessel traffic service centre point to the problem with lack of a standard language in the communication between VTS and ship. The participants state that communication is adjusted to whom they are talking to, and also point out that one should not use too advanced language. The participants in the study believe that much of this can be solved with standardized routines for communication.

Costa, Lundh and MacKinnon (2018) complement previous studies of how communication affect VTS operators' judgements and elaborate on how non-technical communication and information processing influence the VTS operator's decision making. The study highlights how the VTS operator compares the vessel's navigational behaviour with the operator's experience, such as ship types and local waters, and how the VTS operator adapts to the different situations.

Mistrust between VTS operator and navigator/pilot. Brodje, Lundh, Jenvald and Dahlman (2013) studied miscommunication in Swedish vessel traffic service operation. An important aspect of their study is that attitude and communication are central factors for safety in aviation and they explore whether miscommunication is present in the maritime industry. Their study discovers that lack of trust between VTSO and pilots/navigators affects communication and creates a tension in the maritime system.

Lack of time for planning. Praetorius and Hollnagel (2014) describe the VTS as a complex socio-technical system, and more specifically a Joint Cognitive System (JCS). They focus on joint human-machine systems, and how the VTS maintains control over the environment. They state that most systems combine control methods to maintain control in shifting context, and that the ability to maintain a stable state over time is the core of the concept of resilience engineering. Control is then the degree of orderliness in the system, and JCS defines four control modes used by systems:

scrambled, opportunistic, tactical and strategic (Hollnagel and Woods 2005). Table 1 shows characteristics to the control modes.

Table 1: Control Modes and their characteristics (Praetorius and Hollnagel 2014)

Control Mode	Number of Goals	Subjectively Available Time	Evaluation of Outcome	Action Choice
Scrambled	One	Inadequate	Rudimentary	Random
Opportunistic	One or two (competing)	Just adequate	Concrete	Based on habits/ associations
Tactical	Several (limited)	Adequate	Detailed	Based on plans/ rules/ regulations
Strategic	Several	Abundant	Elaborate	Based on models/ predictions

Praetorius and Hollnagel found that VTS JCS operates mainly in the *opportunistic mode*, and many of the VTSOs think that each situation is distinct. Operating in the opportunistic mode provides just adequate time to cope with the tasks and barely have time to do trade-offs between competing goals, usually between safety and efficiency. The operators use their experience from both VTS and their sea-going experience to predict the situation and choose a course of action. They explain that the VTSO's have limited time and possibility to prepare for a vessel entering the VTS area. The main challenge for anticipation of traffic is the limited availability of information about future traffic movements. With more time, they could apply plans, rules, or regulations, such as more extensive use of standard communication phrases, or they could use models or predications such as using slot times for departure or arrival.

3 Theoretical frame of reference

My motivation for the study emerged from what I perceived to be a one-sided focus on the individual autonomous vessel rather than considering the effect of, and interactions on, all maritime systems. In combination with the impression of lack of interest on the effects on humans, this made the wider frame of the research. This motivation led to an ambition of both including humans and to consider system performance in the development of maritime autonomy. This dual focus has been one of my main challenges, but also an important contribution to the thesis. The reason for the challenge is that the ambition finds roots in two different theoretical research traditions. On the one hand, focusing on the effects and interactions on a systems level, points the research to concern *systems*. On the other hand, the importance of human performance, brings the research focus towards *humans*. Consequently, a difficult question which has been asked several times is if my research is systems centred or human centred. This question could in one sense be one of the initial questions to be answered in the study. Despite several attempts to place my research in one of the two research areas I have been reluctant to choose either side. The reason being that a one-sided system centred focus could potentially ignore the strength of humans to make systems work. On the contrary, a human-centred focus might not explore the effects across different systems, as I argue for in a holistic perspective. This is not to say that a system centred method ignores humans, nor that a human centred focus ignores other systems. However, to base the research in one of the areas would underestimate the contribution of either the system or humans.

In the theoretical frame of reference, I present the systems theory and the human factors theory as two separate sub-chapters.

3.1 Systems theory

A fundamental principle for systems theory is to consider the whole rather than parts, which is as *holism* or taking a *holistic perspective*. The idea of applying a holistic perspective for explaining the world could be traced back to 2500 years ago, when Aristotle stated that “the whole is more than the sum of its parts”. Aristotle’s statement explains that we cannot fully understand the world by looking at parts of the world in isolation, but rather need to understand what emerges when the parts of a whole are put together. However, the scientific revolution evolving in the seventeenth century uses the opposite, a reductionist approach. In Descartes’ *Discourse on Method* from 1637, his second of four laws describes that difficulties under examination should be divided into as many parts as possible adequate for solution. By applying such a reductionist approach, scientists experienced remarkable success in continuously explaining more of the relationships in the natural world. Natural science constantly revealed more of the building blocks of our universe, and step by step gained more understanding of the physical world. The success from natural science inspired researchers in other science fields. In the nineteenth century, *naturalism* became the prominent research direction in social science and aimed for value-free, objective and predictive research (Gorton 2010).

In the first half of the twentieth century, critics to the reductionist thinking argued that isolation of parts disregards the phenomena that emerges when the parts are put together to a whole. One of the most prominent advocate for the critics, von Bertalanffy, argued in the late 1920’s that investigation of single parts or processes cannot explain the vital phenomena of living things in its organisation (von Bertalanffy 1929). Von Bertalanffy claimed this to be the germ of the *general systems theory* phrased chiefly by himself, but this neo-Aristotle approach was also developed in parallel by a wide range of other researchers such as Bogdanov, Smuts, Lienau, Barnard, Kohler, Lotka, Volterra, Ashby and Boulding (Rousseau, Billingham, and Wilby 2016; von Bertalanffy 1972). Even though von Bertalanffy is a biologist, and his work is developed in the field of biology, an important aspect of general systems theory is that it is applicable to other fields and to systems in general (von Bertalanffy 1972).

Von Bertalanffy claims that general systems theory is a new basic scientific discipline, a *logico-mathematical* field that defines concepts applicable to systems in general, such as wholeness, emergent and resultant evolution and hierarchical order (von Bertalanffy 1951). Calling the theory logico-mathematical emphasizes the knowledge of relationships that do not exist before we establish the relationship itself. A simple example could be to ask a child if there are more cats in the world than animals. For children who have seen more cats than other animals, they tend to answer cats, since the *relationship* between cats and animals is not established. This emphasis on relationships are both the one of the significant differences between reductionism and holism, and the rationale for holism. Relationships will naturally disappear in the reductionist approach when parts are studied in isolation. Further, the relationship itself is one of the important elements to study in a holistic approach to understand systems. The term logico-mathematical could lead to the conclusion that general systems theory is a purely mathematical theory. However, von Bertalanffy (1972) clarifies that the term could be used for a new paradigm to respond broadly to "system" problems, and not only in mathematical terms. To explain this paradigm, he elaborates on three aspects: systems science, systems technology and systems philosophy:

> **Systems science.** The scientific exploration of applying principles of general systems theory in various sciences, is called systems science. In particular, it is important to explore the 'whole' or 'wholeness' and the interactions in systems in the various fields of science. Different system-theoretical approaches are suggested, such as cybernetics, control theory, game, and decision theory, for responding to the problem of understanding interrelations within a superordinate whole. Systems science also considers *dynamical systems theory*, concerning how systems change over time and how systems respond to disturbances. An important aspect of dynamical systems theory is creating a relation between systems theory and control theory. The purpose of control is to counter the disturbances to a system and maintain its stability. Consequently, the relationship between the system and the environment becomes imperative. The dynamical systems theory uses both internal description and external description of systems. Internal description defines the system's structure in terms of variables and interdependence. External description considers the system as a 'black box' and describes the system's behaviour by its interaction with the environment.
>
> **Systems technology**. Problems caused by the complexity in technology and society is framed as the systems technology aspect. The problem could consist of both 'hardware' and 'software'. Hardware is the use of control technology, automation or similar. While software describes the use of systems concepts and application of systems theory in social, economic, ecological, or similar, problems. In particular, the technological demands open for new concepts and disciplines and the complexity in the new problems calls for a holistic and interdisciplinary approach.
>
> **Systems philosophy.** The introduction of systems as a new scientific paradigm sorts under the aspect of systems philosophy and covers the systems ontology, epistemology, and values. To describe the systems ontology, what systems really are, von Bertalanffy initially distinguishes between real systems and conceptual systems. While real systems are observable and exist independent from an observer, conceptual systems are symbolic relationships such as logic or mathematics. However, von Bertalanffy states that an object or a system is definable by its cohesion and interactions. As such, social systems are also considered as real systems, and he states that the distinction between and real objects or conceptual constructs and systems cannot be drawn.
>
> Miller (1965) distinguishes between conceptual, concrete, and abstracted systems. Conceptual systems are considered, in line with von Bertalanffy, as symbolic relationships such as logic or mathematics. Concrete systems are natural systems or described by Miller (1965, 202) as a *"non-random accumulation of matter-energy, in a region in physical space-time, which is organized into interacting interrelated sub-systems or components"*. While abstracted systems are relationships abstracted by an observer.

> Epistemologically, von Bertalanffy considers systems philosophy as different from the logical positivist direction being predominant the first half of the 20th century. The analytical, linear and reductionist approach of the logical positivists are replaced by investigation of the whole through new models and techniques. An epistemological discussion of how to gain knowledge about social systems has in general followed two directions. One, advocated by Miller (1965), is to focus on the concrete system rather than the abstracted system. The other focuses on abstracted systems, which is the social role rather than the individual, to understand social systems (Parsons 1979). Bailey (1990) sums up the discussion by saying that both directions are necessary and must be studied simultaneously.
>
> Values play an important role in systems philosophy and marks a difference to natural science. Von Bertalanffy underlines that systems philosophy has a humanistic concern and considers symbols, values, and social entities as something 'real' and important for understanding the world.

Systems thinking and systems engineering. The systems theory is the origin of different approaches to analyse systems, and a common term for such approaches is systems thinking (INCOSE 2015). Senge (1990) calls systems thinking the fifth discipline that needs to be developed in parallel with, and unite, the four disciplines personal mastery, mental models, shared visions and team learning to develop a learning organization. The application of systems thinking to create systems is called *systems engineering*. A straight forward description of systems engineering is suggested by Bode (1967), saying that "*system engineering is what systems engineers do"*. However, a more extensive definition is suggested by INCOSE (2015, 11) as:

> *"Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meet user needs."*

The development of systems engineering is by Hossain et al. (2020) described in three phases; the introductory phase of SE from 1926-1960, the SE exploratory phase from 1960-1989, and the SE revolutionary phase from 1990. While the first phase was driven by the interest of understanding how the technology development making systems more complex, the second phase had a more holistic perspective. In this second phase, the systems engineering perspective expanded from complexity caused by systems, to include an economical, and a social perspective (Gorod, Sauser, and Boardman 2008). The revolutionary phase from 1990 refers to systems engineering is being more extensively applied and developed in the industry and in academia, and this is shown by the peaking frequency of studies and by the foundation of the International Council on Systems Engineering (INCOSE) in 1991.

The most prominent ISO-standard covering systems engineering is ISO 15288:2015 (ISO 2015). However, several ISO-standards apply the systems engineering approach or use systems engineering principles (INCOSE 2015) and proves that systems engineering is a recognised approach to manage complexity and change in systems design. Even if many different systems engineering methods, the study does not apply one single method, but follows what Blanchard and Fabrycky (2013) claim to be the common threads of the methods:

1. A top-down approach to see the system as a whole
2. A life-cycle orientation from system design and development to phase-out and disposal
3. Defining system requirements and design criteria

4. An interdisciplinary approach to address all design objectives

The present revolutionary phase shows more and wider application of systems engineering, however, Hossain et al. (2020) highlight three future challenges for systems engineering. First, it necessary to develop the underlying theoretical and conceptual foundations for the systems engineering discipline. Second, more interdisciplinary inclusion of other disciplines is needed for development and application of systems engineering. Third, it is necessary to emphasise the ability to address the emerging class of complex systems and their challenges.

3.2 Human factors theory

Human Factors, human factors and ergonomics, or human factors engineering are all different aspects of what Meister (1999) refers to as the discipline which endeavours to determine the relationship between humans and technology. A discipline that in Nordic countries has been heavily influenced by sociology, in the UK by engineering and in the USA by psychology. In my thesis, I will not differ further between aspects or which traditions that have influenced the discipline. I will use human factors as a term for all and consider a variety of studies as The Human Factors and Ergonomics Society (n.d.) lists: performance, problems encountered in information presentation, detection, and recognition, related action controls workspace arrangements, and skills required.

The humanistic concern in systems philosophy links systems theory and social science, and further, by arguing that systems theory is about wholeness, one could easily argue that systems theory includes human factors. The rationale for discussing the human role in systems, or human factors, is to form a basis for discussing how much, and what, we need to know about humans in a systems perspective.

Both systems theory and human factors agree that most complex human-made systems cannot function without humans (Meister 1999; INCOSE 2015). If we, regardless of belonging to either systems theory or human factors, acknowledge the importance for humans in system performance, we need to answer Meister's (1999) questions of how far do we need to go to analyse human performance to understand how the system functions? To answer this question, we need to turn to his characterisation of the human element. Meister claims that the central elements in human factors are the physical, cognitive, and motivational. Physical aspects include strengths, anthropometry, and sensory and perceptual qualities and limitations. Cognitive aspects are the reason-making processes, such as decision-making. Motivational aspects cover the incentive for performance in various situations.

Accepting that human factors is about the three human elements defined by Meister, which of the elements, and to what level of detail, must we explore to understand the human role in systems? The short answer, supported by Meister, is not to take a behaviourist approach, where the humans are considered as a black box. In this outdated approach, human performance is merely a response to an input. Consequently, we need to know more, and to take a systems perspective to human factors, as we need to understand the wholeness of the human elements. Prior to exploring the three elements further, it is useful to understand the situation in the 1950s, when human factors emerged.

The 1950s was a decade when a push-back on behaviourism affected science fields such as psychology. The strong behaviourism in the 1930s emphasised that psychologists should study the observable and measurable behaviours. However, it became apparent that behaviour could not be explained by stimulus-response alone. Consequently, psychology started to drift from behaviourism to understanding humans as capable of storing and processing information about the environment (Bermúdez 2010). The research of human information-processing was heavily influenced by three researchers. Shannon (1948) studied how information could be measured. He presented mathematical tools for transmission of information and introduced the term 'bit' for measuring information. His work was important for Miller (1956) who used Shannon's basic concepts of information theory to model features of how the mind works. He presented the concept of information channels, and identified our perceptual systems as being information channels. Miller found that our perceptual systems are sensory channels with limited capacity. Broadbent (1958) built on this knowledge to present an information-processing model showing how sensory information is processed, and how selective attention occurs.

Dividing the human element in three distinct parts as physical, cognitive and motivational components is an artificial approach that could easily ignore the interdependencies between the three. However, I have used the components to describe some differences and developments within the three areas.

> **Physical.** To understand sensory, perceptual and motor functions has been important since the origin of human factors as a research field (Meister 1999). The physical ergonomics aspect of human factors would fall under the human element labelled physical. The knowledge of the physical element has led to standards for designing the workplace, considering factors such as lightning, thermal conditions, noise, and interfaces to technical equipment (such as (ISO 2001, 2011)).
>
> **Cognitive.** From a cognitive perspective, the development in the 1950s moved psychology away from behaviourism to understanding organisms as information processors. This shift is a fundamental idea of cognitive science (Bermúdez 2010). On the other hand, information theory did not consider what happens between receiving a message and generating a response, and in the 1960s this gained increasing interest in cognitive psychology. To increase the knowledge of cognition, it soon was realised that we cannot understand human behaviour without considering the context, and particularly the use of existing technologies (Suchman 2007). This is the fundament for the 1980's emergence of Cognitive Systems Engineering (CSE) (Hollnagel and Woods 2005), Distributed Cognition (Hutchins 1995), Situation Awareness (Endsley 1995) and Cognitive Task and Work Analysis (Stanton et al. 2013), which are all based on a shift from structural modelling to functional modelling of human behaviour.
>
> This shift implies an increasing interest in performance of a system, rather than explicit descriptions of how elements of the system communicate. A fundamental contributor to making systems perform, is controlling the system to respond to shifts in the environment. The relationship between the system and the environment stems from von Bertalanffy's (1950) theory on open systems in biology and physics as described in previous section.
>
> Holling (1973) uses the term resilience as a measure of the ability to absorb changes from the environment, or environmental turbulence as Trist calls it (1976). The relationship between an environment and a control system regulating the performance of systems was first described in cybernetics. Ashby presented the Law of Requisite Variety where he states that *''only variety in R can force down the variety due to D; variety can destroy variety,''* (1956, 207). What Ashby points to is that the control system must have a variety in its performance as large or larger than the demands of the environment. The Law of Requisite variety has been important to describe the properties of the control system. Since humans are superior when it comes to interpretation and adaptation, it is necessary to understand, and facilitate for, human performance variability. In his interpretation of Ashby, Flach (2012) relates variety with complexity, uncertainty and change, while reducing variety is related to the construct of regulation, control and adaption. As such, the cognitive element of human factors is about understanding human performance in context, and how humans cope in a complex environment.
>
> **Motivational**. The motivational element considers incentives for human performance. Like the cognitive element, the context needs to be considered. The awareness of how underlying causes affect human performance has evolved during the last 50 years, often following tragic accidents. In the 1950's and 60's, accidents were explained by technical failures and human errors. If technical failures were ruled out, investigations pointed to human errors such as negligence or bad judgement. In the 1970's, and accelerated by the aviation accident at Tenerife, a broader attention to cooperation between operators was given. Cockpit Resource

> Management was one of the responses to the challenge. In the 1980's several major accidents occurred, such as the nuclear accident at Chernobyl, the capsizing of the ferry Herald of Free Enterprise, the aviation accident at Dryden and the explosion of the space ferry Challenger. All these accidents brought attention to how organisational causes affect human performance. A distinction between active and latent failures was made to show that failures at the blunt end could lead to errors in the sharp end. Models such as the swiss-cheese, indicating barriers with the potential to be degraded exist on all levels from organisational to individual level (Reason 1997). The mind-set affected the socio-technical systems theory, and models on socio-technical levels layers were developed to show how the individual is affected (Rasmussen 2000; Vicente 1999).

Human factors and design. The core of human factors in design is to consider humans when designing and to understand the human strengths, weaknesses, and performance variability by considering physical, cognitive, and motivations factors. Human factors challenges emerge in the boundary between humans and systems, and human factors in design is an iteration between designing and testing in a systems approach (Stanton et al. 2013). One approach that emphasises such iterative approach is human-centred design. This approach aims to develop systems with improved quality by increasing productivity, increasing usability, improving user experience, reducing stress, providing competitive advantage and contribute to sustainable objectives. To achieve this increased quality, the approach emphasises to understand users, involving users, iteratively refine the design by user evaluation, address user experience and include multidisciplinary skills (ISO 2010).

The Human Factors field has a large variety of methods to support the human-centred design approach and each method need to be chosen based on the need of the analysis. For example, understanding users can relate to the physical aspect and ergonomics, or it could be more relevant to understand the cognitive aspect in problem solving. Consequently, a large number of human factors methods exist to support different needs. In this study, the human-centred design process is applied, while cognitive task analysis, user-involvement, and the use of focus groups are more specific methods applied in the process. Subsequently, the study explores performance variability and connects this to organisational and external influence on such variability.

Systems theory and human factors theory. The theoretical framework of using both systems theory and human factors points to several similarities, and as such, a separate presentation of systems theory and human factors could be artificial. A significant overlap is *resilience* that could be found in both systems theory and human factors theory. The common ground is to make systems resilient to unpredicted changes and to use human performance as a valuable resource. To operationalise the term in my thesis, I use 'safe coexistence' as a synonym to resilience in my research context. If the system is resilient, vessels will coexist safely, and vice versa. How to implement the theoretical framework to my research is related to the philosophical foundation. The next chapter will explain how the philosophical stance has affected my research approach.

4 Philosophical foundation

In my study, I use systems theory and human factors theory to explore my research issue of how a systems perspective could enable for autonomy in the maritime industry. In the theoretical framework I have claimed that safe coexistence is an operationalisation of resilience and an important overlap between systems theory and human factors theory. In the following chapter I explain the philosophical foundation of the thesis and how I link safe coexistence and my system of interest, the VTS, to the causality between systems perspective and maritime autonomy. Further, the chapter delineates some of the challenges I have come up against in my project and how understanding philosophical stances and the role of values in social science have been pivotal.

4.1 Ontological and epistemological stance of my research

By operationalising resilience as safe coexistence, an important part of the research is to answer the ontological question of what safe coexistence is, and the epistemological question of how to have knowledge about safe coexistence. Ontology is the *theory of being as being* and epistemology is *theory of knowledge* (Delanty and Strydom 2003). These fundamental questions caused some troubled waters in the research, and these questions call for an increased awareness of the role of values in my research. The following section refers to the challenges I have met and the choices I have made in my research approach.

The motivation for the study is to present an alternative perspective to the technology-focused development of the maritime industry. By arguing for the importance of understanding the role of humans, the study aims to explore the new interactions between the decision-makers in a future maritime traffic system. Specifically, I focus on how the future Vessel Traffic Services (VTS) could facilitate for safe coexistence between conventional vessels and autonomous vessels. This places my study within social science, where safe coexistence is perceived as a social phenomenon.

Naturalism and anti-naturalism in social science. Social phenomena and values have been explained differently throughout history and between various philosophical traditions. Naturalism and anti-naturalism are two main traditions that are important for understanding social science in general, and social phenomena and values more specific. The difference between the traditions are founded in how they relate to natural science. Natural science has been central to the understanding of, and control over, the natural world by being progressive. Natural science has increased in-depth knowledge, being predictive and being consensual, and *naturalism* is used for the philosophical directions that aim to apply methods from natural science to social science. The other tradition, *anti-naturalism,* challenges the naturalism's value-free, objective, and predictive research (Gorton 2010).

One of the prominent representatives of naturalism and logical positivism, Durkheim (1858-1917), argues that social facts are phenomena external to the individual that have a power of coercion that controls him or her (Durkheim 1895). He claims that this perspective of social facts could avoid confusion between sociology, being about external phenomena and biological phenomena, concerning representation and action, and psychological phenomena, being about individual consciousness. Hence, Durkheim states that social facts could be studied externally and objectively, and being in line with Mill's statement that scientific knowledge of social phenomena could only be found by applying methods and logic of natural science (Mills 1859).

The naturalistic tradition and challenges for my research. The initial phase of the research followed a naturalistic tradition. With access to several navigation simulators, the original intent was to set up scenarios and adjust the control level to identify the 'best' solution. After having discussions and performing a literature review, this became more complicated than expected. The challenge of describing safe coexistence became increasingly difficult, and ironically, more complicated when gaining more knowledge about different aspects of the safety. No single definition of safety or safe coexistence between vessels could be found, and the definitions that were found spanned from calculating safety distances between vessels to the measuring the stress level of the individual navigator. Testing various measures of safe coexistence in a simulator showed that situations that were unsafe based on calculations were experienced as safe by navigators. Other situations showed the opposite, situations calculated to be safe, were unsafe in accordance with navigators. The search for the answer of what safety is, and how to measure it, seemed to be an eternal struggle.

Social reality, an anti-naturalistic tradition. A century after Durkheim's work, Searle (1995, 2006a) presents an underlying logical structure for social reality, of what constitutes social facts, where he explores social ontology as both human actions and the physical objectives in the natural world. An interesting debate about Searle's work is the convergence with Durkheim. This debate is well summarised by Lukes (2007), showing that they share more or less the same perspective on the role of collective representations to account for social facts, the unity of nature, the ability to obtain objective knowledge of social facts. Gross (2006, 46) even claims Searle's work to be "*unacknowledged and unreconstructed Durkheimianism".* Searle (2006b) rejects the criticism and lists 12 distinctions of the concept between himself and Durkheim. Some of the differences are that Durkheim has a directly opposite view of the relationship between the individual and social fact. Further, Searle states that Durkheim believes that social facts are external to the individual, while Searle considers social facts are different from institutional facts, and that collective intentionality is entirely in the individual minds. This thesis will not elaborate further on the discussion of convergence, except from noting that even though some claim similarities to Durkheim, this perspective is not shared by Searle.

Searle (2006a) discusses the 'problem of social ontology', based on his work on 'The Construction of Social Reality' (Searle 1995). Searle says that the social phenomena being discussed are social objects (e.g. a nation), social facts (e.g. a citizen of a nation), and social processes and events (e.g. electing a president for that nation). However, the problem he emphasises is if we assume the world to consist of entirely physical particles, how can humans or animals create a social reality? Searle provides a short answer to this question; that social reality exists only because we think it exists, and his work is based on describing a logical structure of how we create social reality.

Searle (2006a) highlights two fundamental distinctions within the structure of social reality. The first is between the terms *observer independent* and *observer relative* to differentiate between social science and natural science. He states that, in general, observer independent are features that exist independently of us, while observer relative are features that depend on us to exist. Hence, the observer independent features are mainly related to the natural sciences, while observer relative features are related to the social sciences. However, the use of the term 'observer' is criticised by Lukes (2006), and he suggests to use 'participant' to avoid confusion; an observer could be something outside, not involved in the actual interaction with the environment. The second fundamental distinction is about objectivity and subjectivity related to observer relativity. Searle states (2006a, 15) "*observer relativity implies ontological subjectivity but ontological subjectivity does not preclude epistemic objectivity"*. The point Searle is making is that epistemic objectivity does not require ontological objectivity, and if it did, social science would not be possible. Hence, an ontological subjective phenomenon could have both an epistemic objective and subjective claim.

The ontological and epistemological stance on safe coexistence. In Durkheim's perspective, safe coexistence could be perceived as a social fact and being an external coercive power, and it should be possible to identify an objective measure of safe coexistence. However, by taking such a perspective, I might meet the same criticism as positivism; that safe coexistence is something external to humans and could be studied objectively in isolation. A different approach is to consider Searle's social reality of the maritime traffic system and to perceive safe coexistence between autonomous and conventional vessels as a social phenomenon of collective intentionality. Hence, the coexistence of the vessels is an ontologically subjective phenomenon that opens for both epistemic objective and subjective claims. Figure 2 shows how my research could be described following Searle's claims of social reality.

	Objectivity	**Subjectivity**
Ontological	Feature of phenomena that can exist independently of being experienced *Vessels, Vessel Traffic Services*	Feature of phenomena that cannot exist independently of being experienced *Safe coexistence of vessels*
Epistemic	Feature of claims that are true or false independently of personal attitudes *Distance between vessels*	Feature of claims that are not true or false independently of personal attitudes *The coexistence of vessels is safe*

Figure 2: Coexistence of vessels can be an ontological subjective phenomenon that is explored through epistemic objective and subjective claims

Figure 2 shows an example of using distance between vessels as an epistemic objective claim. As separation is an essential safety parameter in other traffic systems, I considered this as relevant for my study. The problem, as already described, was that the there was no correspondence between distance in nautical miles and the navigator's feeling of a safe situation, neither when tested in a simulator nor in discussions with navigators. The most common response when trying to define claims that prove safe coexistence, was 'it depends'. This shows that I either had to find more and better objective claims to explain the 'it depends' or I had to search for other type of claims.

The other option to gain knowledge of safe coexistence is to find epistemic subjective claims. Even though a large variety of claims could be related to safety, it is problematic to decide which to pursue. The starting point for the research is therefore to create a comparison with the existing coexistence between vessels stating that the coexistence between autonomous and conventional vessel should be as safe or safer than the existing coexistence between conventional vessels. In isolation, this does not provide more clarity of what to look for, since it is a goal-oriented claim. However, it leads to a requirement of a methodology that first understands what the important aspects of present safe coexistence are, and further, how these aspects need to be adapted to a future situation.

A consequence for my research is that I had to find support in a methodology considering both resilient systems and the human contribution to resilience. Since my initial idea of using some commonly agreed epistemic objective claims to assess different solutions was not possible, I had to make a stronger effort in understanding the existing situation, explaining the interconnections in the maritime traffic system before designing potential future solutions.

In sum, my thesis falls under social science and follows an anti-naturalistic tradition. Even though my stance was close to a positive logistic research approach when commencing the project, I have shifted to an interpretivist approach. Taylor (1985) refers to interpretation as an attempt to make clear or to make sense of an object of study. I associate my research with hermeneutical interpretivism, who aims to uncover unseen causal processes through understanding both the researcher's role and the society under research (Gorton 2010).

4.2 The role of values in my project

The concept of values is allegedly one of the reasons that the social sciences did not see the same empirical success as the natural sciences in the 18th and 19th centuries. During this time period, values were perceived to cause results to be less reliable and social science was not able to demonstrate the same value-neutrality as natural science (Douglas 2014). In the first half of the 20th century, Weber (1949), who emphasised objectivity in social science, engineered a strategy where values should affect the choice of research area, but not the analysis and the results. The perspective changed further during the century, as the feminist perspective shows. A modern feminist perspective aims to produce better knowledge by advocating methods that "*do require attending to features (such as gender, race and class) of both the knower and those whom they hope to know*" (Crasnow 2014, 146). As such, the development of values shows it is increasingly accepted and needed in social science. Hence, values in social science are essential to understand my role in the research project and to know the legitimate and illegitimate roles of values in the research. Specifically, it is interesting to ask how aware I have been on the role of values in research and how my background has affected my direction of research.

Douglas (2014) describes values as normative or emotive tacit or explicit commitments people hold. She refers to a common distinction of epistemic/cognitive values and moral/social life values. Where the first have traditionally been considered acceptable, the latter have been more problematic. However, as Douglas states, it is important to decide which values should be in and which should be out, and additionally to understand where in the process values influences the research. Douglas (2014) refers to three entry points for values in research: the direction of research, scientific inference, and scientific language, and she describes these as:

> **The direction of research** is a consequence of the scientist's background, interests, and external circumstances (e.g. funding). The point made by Douglas is convergent to Weber (1949) argument for researchers have to know what is significant to know what to study. The values affecting the direction of research could be legitimate roles, such as ethical, personal, aesthetic, and epistemic choices of the research. However, illegitimate roles of values could be found if researchers produce methodologies that ensure a particular result.
>
> **Values and inference** are another entry point for understanding how the social values of scientists affect their interpretation of the available evidence. Values can have a negative impact on reasoning, either by confirming the scientist's pre-determined perspective by producing flawed data or being so strongly affected by values that they distort how to analyse data. However, values could indirectly affect science in the uncertainty that logically follows of all claims that not follow deductively from the evidence. Douglas' example is if 80 of 100 people in a study are right-handed, the direct deductive conclusion is obviously that 80% of *that* group is right-handed. However, the research becomes interesting when the group is a sample of a larger population and could conclude that 80% of the *entire population* is right-handed. The shift from direct deductive results from one specific group to a generalisation of a population inevitably creates some uncertainty. Such as if the sampling is representative or if the sample is skewed. The societal and ethical values are important to decide which consequences of error such uncertainty will lead to.
>
> **Values and language** points to how language brings value connotations into science. Dupré's (2007) discussion of how the term 'rape' is used to describe animal behaviour is used as an example of how language could poorly describe a situation. While the term in the human life is connected to power, violence, and control, the animal behaviour is linked to reproductive urges. The example shows that value-laden terms could, if used wrongly, affect the research.

The argument Douglas (2014) makes in the abovementioned points, is that the role of values has shifted from the ideal of being value-neutral, to play a role through the entire scientific process. Consequently, the values should be openly discussed to ensure that values are given a legitimate role, while illegitimate roles are avoided.

To understand the challenges more in depth, this logic could be combined with the role of values. The presented perspective of Douglas shows that values could play a role in the entire process of science. To direct the research, background was highlighted as an important value.

I have a background from aviation and air traffic management which could amplify the issue of a mismatch between how I perceived safe coexistence and the navigator's expectation of safe coexistence. In aviation, epistemic objective claims are prominent, hence, methodologies supporting these claims are preferred. A similar situation as above would in aviation be to say that the distance between two aircraft is 5 nautical miles *therefore* it is commonly accepted and undisputable to be safe. Contrary, a distance of 4.9 nautical miles is equally accepted to be unsafe. To a certain extent, the subjective epistemic claims are not considered. Neither are the role of values, and consequently my background is in line with logical positivists. This could explain some of the challenges in the beginning of the research. Further, this underlines that if my background were to direct me to continue to use epistemic objective claims with associated methodologies to describe maritime safe coexistence, the risk of getting a result that would not be recognised in the maritime industry would increase.

It is imperative to highlight that this is not an argument for aviation being on wrong track, but to create a better understanding of how I need to consider my background in this research project. The comparison of a maritime approach and an aviation approach to safety raises an interesting issue of Searle's logical structure: even if ontological subjectivity does not preclude either epistemic or subjective objectivity, could an ontological subjective phenomenon be fully understood by either epistemic objective *or* subjective claims, or does it require a combination of both? With one foot in maritime and one in aviation, it could be possible to see benefits from a combination of both, but this is not something pursued further in this research project.

4.3 Causation

The main research question is whether a systems perspective can tailor for maritime autonomy. To make a scientific exploration of the research question, a causation between a systems perspective and maritime autonomy needs to be shown. Hence, I need to explore the causation by considering the systems perspective being as the *cause* and maritime autonomy the *effect*.

Figure 3: The main issue of the thesis is to explore causality between systems perspective and maritime autonomy

Hall (2004) categorises causation in two basic varieties, one is dependence, the other production. Dependence is the counterfactual dependence between distinct events; if a cause exists, the effect will occur, or the opposite, if a cause does not exist the effect will not occur. The other variety, production, is when a cause helps to generate, produce, or bring about an event. Cartwright (2014) describes four main ideas to characterise causation which applies to both dependence and production:

- Probabilistic association is causation where more effect is present when a cause is present than when if the cause was absent.
- Manipulation is described as manipulating the effect in a predictable way, and when no other cause than the manipulated cause affects the effect, it is 'manipulation in the right way' and called intervention.
- Mechanism is a causal process between cause and effect, where the process is broken up in sequence of small steps to understand a larger whole. Causation is explored by keeping the causal process invariant and manipulating the cause to change the effect. Mechanism emphasises a systems approach, where the underlying structure or social structure is understood.
- Power is the capacity to create a causation. Four assumptions are used to describe power: A system can have a certain power, but not display it. The power is displayed when conditions are right. What happens when power is displayed depends on the setting. How a power operates in a situation will depend on the display of the power.

The main research question – to take a systems perspective to enable maritime autonomy – is a broad question and needs further details to discuss causality. To do so, I use a mechanism explanation approach and consider the causality between a future VTS and safe coexistence as shown in Figure 4.

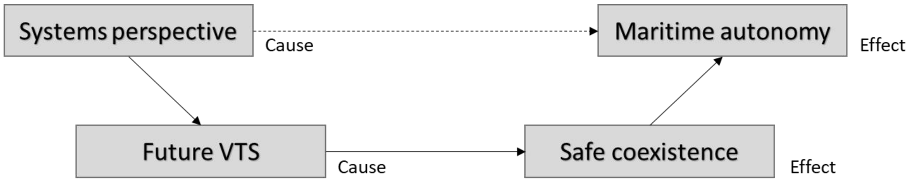


Figure 4: Rather than exploring causality between systems perspective and maritime autonomy, the study focuses on the causality between future VTS and safe coexistence.

To discuss causality, I take a detour from the direct causation between a systems perspective and maritime autonomy to the causation between the future VTS and safe coexistence. The rationale for such detour is that the systems perspective has led me to focus on other interactions than the vessel in isolation, and the system of interest in the study is the VTS. Further, I use the principle of equivalence as a decisive objective for maritime autonomy - meaning that if future coexistence is as safe as current coexistence, I consider it likely that maritime autonomy is accepted. Consequently, I explore a causality between a future VTS and a safe coexistence.

The relationship between systems perspective and the future VTS and further, between safe coexistence and maritime autonomy, is explained, but causality is not demonstrated in this study. As such, the route visualised in Figure 4 is a mechanism explanation, but not a mechanism causality.

To explore causality between future VTS and safe coexistence I use intervention. The description of intervention of being a manipulation in the right way, is a reminder that there are pitfalls to be aware of. Woodward (2003, 94) claims that intervention is a manipulation approach to causation as follows:

> *"Intervention on a variable X with respect to some second variable Y is a causal process that changes the value of X in an appropriately exogenous way, so that if a change in the value Y occurs only in virtue if the change in the value of X and not through some other causal route".*

Intervention in a social setting is challenging, and in particular it is difficult to isolate the change due to intervention from other changes. Applying Woodward's description to my study, the future VTS is variable X and safe coexistence is variable Y. The change of Y due to X could be easier to isolate in a futures study as it is possible to reduce the impact of external effects. However, the validity is relying on the research being able to describe all *assumptions* when making changes to the cause. Hence, the significant interpretations and assumptions need to be collected during the research and support the interpretative stance in the study.

In sum, the causality in the study is explored by intervention on the cause, the future VTS, to reach the desired effect: safe coexistence. I use a production causality, where the objective is to describe how the future VTS can produce a safe coexistence in the maritime study. I consider the approach to be applicable since the study is about a future situation, where it is possible to make an intervention on the cause while keeping the causation invariant by eliminating other causes.

5 Methodology

The previous chapter explains why my study falls within the social sciences and justifies the ontological and epistemological stance of my research. The methodology chapter describes how this stance translates to a research strategy that answers the research questions in the study.

The study is a qualitative study in a hermeneutical interpretivist direction. I intervene on the future VTS and explain the effect on the epistemic subjective claims of safe coexistence. Consequently, the methodology explains *how to intervene* in the system of the VTS, and *how to see effects* on the coexistence. In addition to explaining the research strategy, the methodology chapter provides a reliability and validity discussion.

The stance of my research leads to some overall requirements for the methodology:

1. **A valid and reliable design research methodology.** The overall research question for the study is how a systems perspective can enable for maritime autonomy, this is answered by discussing the causality between the future VTS and safe coexistence. As I intervene on the VTS to identify a causality with safe coexistence, I am *designing* a future VTS that is intended to meet a requirement. As such, a *design research methodology* is needed to support the design research.
2. **Consider interaction and participation**. The philosophical stance of hermeneutical interpretivism underlines the importance of understanding the role of values in my research. The purpose of this understanding is to make values play a *legitimate* part in my research. Garrison (1996, 434) refers to this as *"the point is not to free ourselves of all prejudice, but to examine our historically inherited and unreflectively held prejudices and alter those that disable our efforts to understand others and ourselves"*. To gain such understanding, the hermeneutical tradition points to interaction and a participative dialogic process (Howell 2015). Consequently, a requirement for the methodology is a *dialogic process for knowing what to intervene and to see effects*.
3. **Iteration between parts and the whole**. A different implication of the hermeneutical interpretivism is the iteration between the whole and the parts (Howell 2015). In my theoretical framework, the dual focus is seen by considering the system *and* the humans. Consequently, my methodology must translate the hermeneutical stance to a hermeneutical method that encompass an *iteration between the system and humans*.

The methodology for the study is presented in four sub-chapters:

Chapter 5.1 *Research methodologies* explains how a methodology for research design supports a complementary mindset between systems thinking and design thinking. Further, a suggested iteration between systems engineering and human-centred design is presented.

Chapter 5.2 *Research approach* links the research design to my research questions. Subsequently, it lists the research methods and deliveries for each research design phase.

Chapter 5.3 *Research methods* outlines the methods applied in the study.

Chapter 5.4 *Reliability and validity* is discussed in the last section of the chapter.

5.1 Research methodologies

The research methodology in the study is a combination of the Design Research Methodology (DRM) by Blessing and Chakrabarti (2009) to define the research phases and objectives, and the complementary mindset defined by Lewrick, Link and Leifer (2018) to detail systems engineering and human-centred activities.

5.1.1 The Design Research Methodology (DRM)

Blessing and Chakrabarti (2009) describe design as the process to identify a need and develops a solution to fulfil the need. They propose *a Design Research Methodology (DRM)* to make design research more effective and efficient. This methodology supports setting up a research design that answers the research questions in a study. As Blessing and Chakrabarti highlights, such methodology can only support the process, while every researcher must make their research process unique.

The DRM has four stages: Research Clarification, Descriptive Study I, Prescriptive Study, and Descriptive Study II as visualised in Figure 5. In my study, I have used the methodological framework in the DRM to define research questions, research activities and deliveries for each stage in the framework.

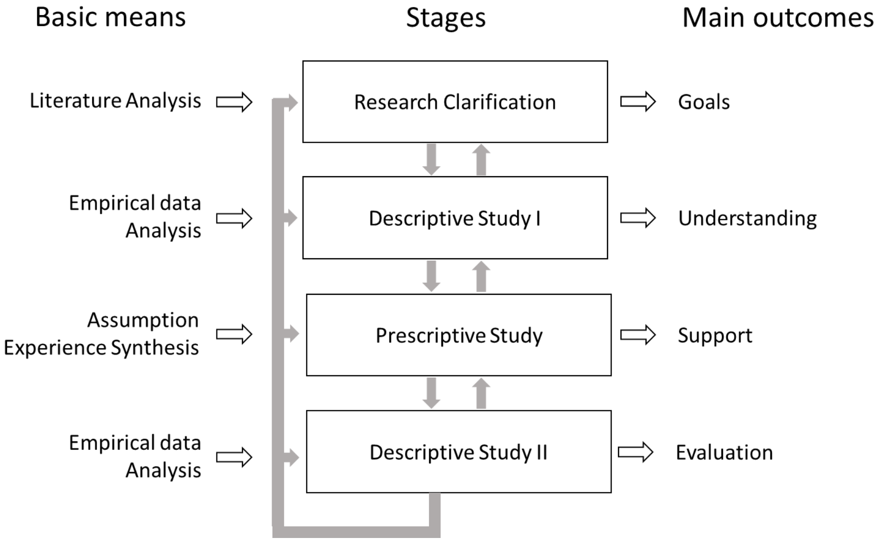


Figure 5: The Design Research Methodology have been used to define research questions and research approach. Adapted from Blessing and Chakrabarti (2009)

Research Clarification (RC). This stage identifies the goals of the research, including main research questions and sub-research questions. An initial picture of the existing situation and of the desired situation are to be defined.

Descriptive Study I (DS I). The Descriptive Study I will obtain a better understanding of the existing situation and what to address to improve the existing situation.

Prescriptive Study (PS). The Prescriptive study aims to use the knowledge from DS I to decide on the most suitable factors to be addressed to give most impact to reach the desired situation.

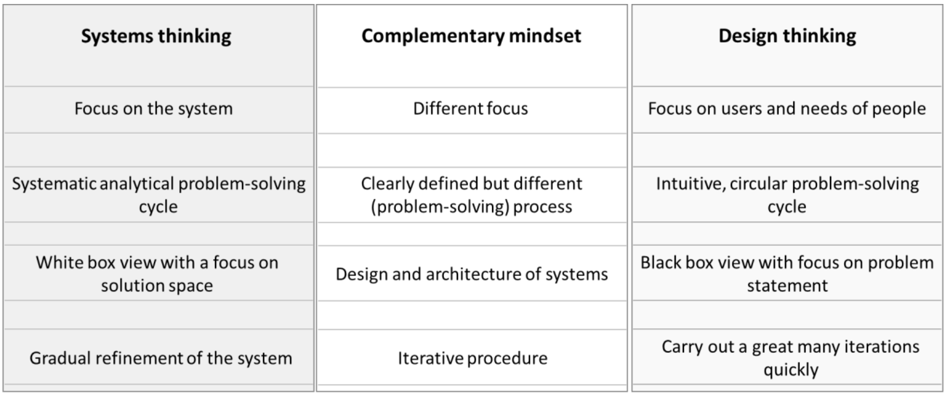
Descriptive Study II (DS II). The Descriptive Study II identifies if the factors support reaching the desired situation is considered in the final phase. This includes evaluating if the factors create a new situation that did not exist before.

5.1.2 A complementary mindset between systems thinking and design thinking

To consider the required iteration, interaction, and participation, the study has combined methodologies of designing for systems and for designing for humans.

A complementary mindset. Lewrick, Link and Leifer (2018) state that to support holistic solutions one should combine systems thinking and design thinking. They describe systems thinking as similar to systems engineering and define “system” as interaction of several components in larger unit and its environment. Further, they describe design thinking as being similar to Human-Centred Design.

They claim that a complementary mindset between systems and design thinking results in new opportunities and better problem solutions. Figure 6 describes how they see the two mindsets could support one, complementary, mindset.



Systems thinking	**Complementary mindset**	**Design thinking**
Focus on the system	Different focus	Focus on users and needs of people
Systematic analytical problem-solving cycle	Clearly defined but different (problem-solving) process	Intuitive, circular problem-solving cycle
White box view with a focus on solution space	Design and architecture of systems	Black box view with focus on problem statement
Gradual refinement of the system	Iterative procedure	Carry out a great many iterations quickly

Figure 6: Lewrick, Link and Leifer describe a complementary mindset between systems and design thinking

Lewrick et. al (2018) argue that such complementary mindset needs to be applied more and more to design future complex systems. Further, they claim that design thinkers could arrive at new solution approaches being brilliant in their simplicity, focus on system-in-systems aligned to individuals in terms of empathy, apply iterative approach to build simple prototypes during problem solving, and “doing it” rather than plan for a long time. On the other hand, they claim that systems thinkers could bring awareness of the solution as a part of a larger system and its environment, to identify and discuss stakeholders for the whole system and to address the problem space and relationships between actors. They claim that the approaches of the two mindsets are convergent and suggest switching back and forth between them to arrive at solutions based on a common mindset (Figure 7).

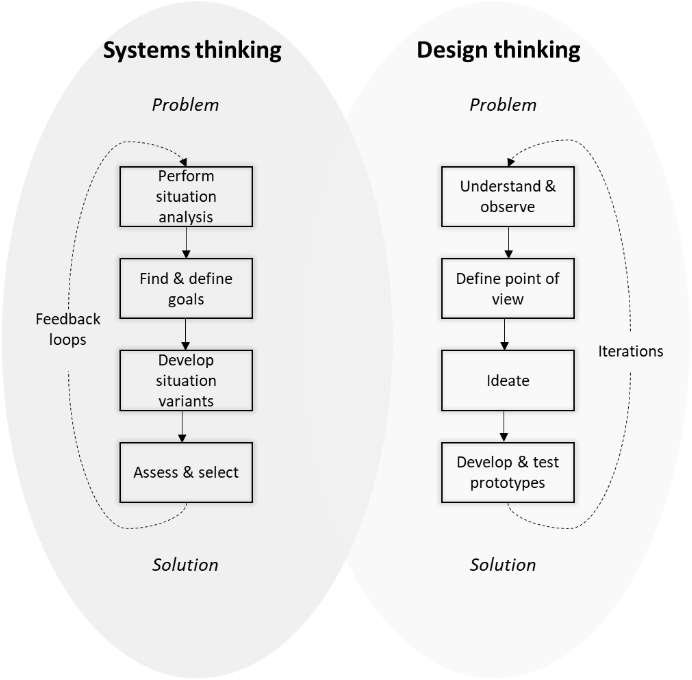


Figure 7: Lewrick et al. (2018) *present the convergence between the systems thinking and design thinking approach and suggest to switch between the two to identify solutions for future, complex systems*

To expand Figure 7, the link between systems thinking and systems engineering, and the link between design thinking and human-centred design thinking explained by Lewrick et. al (2018), is further explored.

A variety of systems engineering approaches exist. Most approaches follow a design process with a gradual refinement of the system and describes the system to follow a life cycle from initiation to retirement. Figure 8 shows a generic life cycle of a system (ISO 2018).

Concept Stage	Development stage	Production stage	Utilization stage	Support stage	Retirement stage

Figure 8: A generic life cycle of systems (ISO 2018)*. This study concentrates on the concept stage.*

The solution the study aims for is not to develop or produce a system. As such, the relevant stage of the life cycle is the *concept stage*. ISO 24748-1:2018 details activities and expected outcomes for the concept stage and states that the principal purposes of the concept stage are to identify stakeholder's needs, explore concepts and propose viable solutions (ISO 2018).

ISO 9241-210:2010 lists principles and activities for a human-centred design approach. The ISO standard presents perspectives that could be integrated in various design processes. The human-centred design approach are based on an explicit understanding of users, tasks and environment, involving users in design and development, user-centred evaluation driving and refining the design, iterations between activities, involving the whole user experience, and including multidisciplinary skills and perspectives (ISO 2010). Figure 9 visualises the suggested activities in a human-centred approach and underlines the importance of iterations while showing the flexibility of potential iterations between all activities.

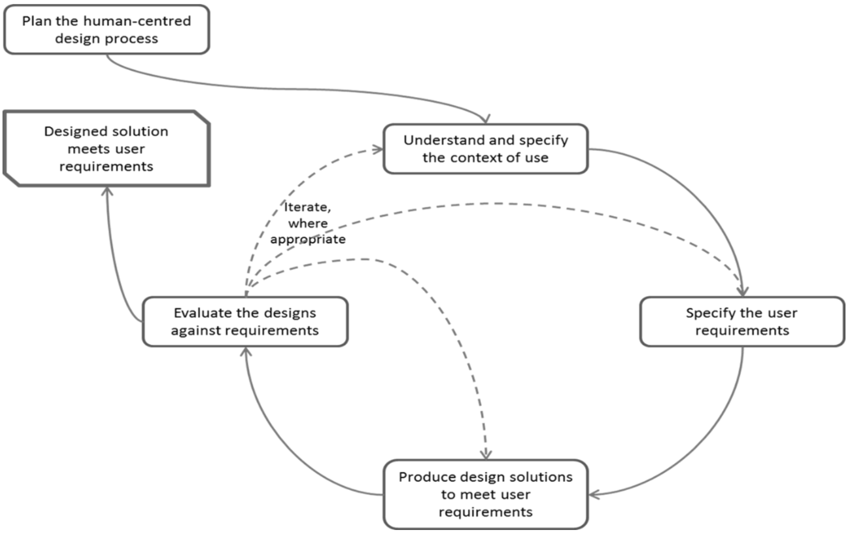


Figure 9: Human-centred design activities adapted from ISO 9241-210:2010 (2010)

5.1.3 A research methodology considering systems and humans

The study has combined the stages from the DRM with the complementary mindset between systems thinking and design thinking. The steps are operationalised by detailing the systems engineering activities from the concept stage and output of human-centred design activities. The Systems Engineering Handbook (INCOSE 2015) and the ISO/IEC standard for Human-centred design for interactive systems (ISO 2010) bring more details of the activities in each phase:

Phase 1: Perform situation analysis / Understand and observe

In systems engineering the first phase is initiated by new ideas or enabling technologies and how these could affect organizational capabilities, opportunities or stakeholder needs. In the early stage, preliminary concepts are explored by analysing technological risks and technology readiness levels focusing on problem and solution space, which is what being possible and what is not.

Human-centred design starts with identifying the context of use by characterising users, tasks, and the organisational, technical, and physical environment. The knowledge of the existing systems could be valid for defining the context for future systems. The description of context of use includes: users and stakeholders groups, characteristics of the users or groups of users, goals and tasks of the users, and the environment of the system.

Phase 2: Find and define goal / Define point of view

Systems thinking emphasizes to identify business or mission requirements and stakeholders needs. Additionally, one should estimate cost and schedule for the development.

In human-centred design the specification of user requirements and stakeholder needs are significant activities. An explicit statement of user requirements in relation to the intended context and business objectives is a requirement.

Phase 3: Develop situation variants / Ideate

Systems thinking suggests identifying multiple candidates for a concept that could offer new capabilities, enhanced overall performance or reduced stakeholder cost. In this phase mock-ups may be used for understanding and preparation for testing.

Human-centred design suggests identifying solutions with a good user experience. This is achievable by following principles for design, designing how tasks could be achieved in interaction with the system, making design solutions more concrete (using scenarios, simulations or similar), altering design solutions based on feedback, and communicating the design solutions to the responsible for implementation.

Phase 4: Assess and select / Design and test prototypes

In systems thinking, the phase includes testing and evaluation of candidates of concepts. Models and prototypes are considered essential for feasibility studies, understanding stakeholder needs, architectural trade-offs, and identifying risks and opportunities. The output in the concept stage in systems thinking is a clearer understanding of the business or mission requirements and stakeholder needs, aligning requirements with stakeholder expectation.

Human-centred design evaluates design early in projects to better understand user-needs. The user-centred evaluation aims to collect new information about user needs, provide feedback on strength and weaknesses of the design solution, assess if requirements are achieved, and establish baselines to compare designs.

Lewrick et. al claim that systems thinking is a gradual refinement of the system as opposed to the many iterations of design thinking. However, systems engineering is to a large extent an iterative process (INCOSE 2015) and systems engineering methods such as Model Based Systems Engineering are based on iterations rather than linearity (Long and Scott 2011). As such, iterations are an important part of systems thinking, design thinking, and in DRM, and even though the methodology is presented in sequence, the several iterations throughout the research is necessary.

Table 2 presents a combination of the DRM stages with the systems thinking and design thinking, including systems engineering activities and human-centred design activities.

Table 2: The DRM stages combined with system thinking and design thinking activities

DRM stage	Systems thinking	Systems engineering activities in the concept stage	Design thinking	Human-centred activities
Research Clarification	Perform situation analysis	Define problem space (exploratory research or concept selection) Characterize solution space	Understand and observe	Context of use description
Descriptive Study I (DS I)	Find and define goals	Identify stakeholders' needs	Define point of view	Context of use specification

				User needs description User requirements specification
Prescriptive Study (PS)	Develop situation variants	Explore ideas and technologies	Ideate	User interaction specification User interface specification Implemented user interface
Descriptive Study II (DS II)	Assess and select	Explore feasible concepts Propose viable solutions	Develop and test prototypes	Evaluation results Conformance tests results Long-term monitoring results

5.2 Research approach

The research approach for the study follows the stages in the Design Research Methodology (DRM). The rationale for each research stage is a combination of the DRM objectives, the systems engineering activities and the human-centred design activities. Consequently, each stage has an introductory text explaining the emphasis for the stage, followed by the research questions, research methods and deliveries. The research methods are briefly presented in this chapter and discussed more in detail in the subsequent chapter.

Table 3: The research approach in the study

Stage 1: Research Clarification

The first stage of the research reviewed literature to gain a better understanding of the area under research. During this stage, the motivation for the study was translated to concrete research questions. The research clarification has emphasised how autonomy being a technology-driven development can enable for new opportunities.

A prerequisite for discussing the development is to discuss the term autonomy. Further, the motivation for the study is closely related to the human role, and as such, the human role in maritime autonomy is discussed.

Research Question	Research methods	Deliveries
What is the human role in the future maritime system? a) What is autonomy? b) How could a systemic human-technology	Review of literature: Automation, autonomy, human and automation, responsibility and authority	Paper: "A Human Perspective on Maritime Autonomy" in Augmented Cognition: Users and Contexts (2018)

<table>
<tr><td>approach in maritime autonomy be adopted?</td><td></td><td>Presentation at Human-Computer Interaction International Conference, Las Vegas, July 2018

Presentation at E-nav Conference, Oslo, September 2018</td></tr>
<tr><td colspan="3"><u>Stage 2: Descriptive Study I</u>

The second research stage focused on obtaining a better understanding of the existing role of the VTS viewed as a control system in the maritime industry. Defining requirements is important from both systems engineering and human-centred design perspectives.

The study has in research question 2 a) described the role from a systems perspective by exploring the relationships within the maritime system. Further, the VTS role is in research question 2 b) described in a human-centred perspective by unpacking how the VTS operators cope in a complex work situation.</td></tr>
<tr><td><i>What is the Vessel Traffic Services’ role in the maritime system?</i>

a) How do the VTS contribute to the maritime traffic system?
b) How do VTS operators use expert knowledge and strategies in the interaction with vessels?</td><td>Review of literature:
VTS procedures

Field study:
Cognitive Task analysis of VTS operators at Kvitsøy VTS

Review of literature:
Literature related to traffic systems and human responsibility for system performance</td><td>Paper: “How vessel traffic service operators cope with complexity – only human performance absorbs human performance” in Theoretical Issues in Ergonomics Science (2019)

Presentation at European Safety and Reliability Association Conference, Oslo, March 2019

Presentation at IALA VTS47 meeting, Paris, September 2019</td></tr>
<tr><td colspan="3"><u>Stage 3: Prescriptive Study</u>
The third stage of the research explored what aspects would be important to design a future VTS that contributes to safe coexistence. The results from the DS I was used to describe more in detail the future role of the VTS, and a design process considering both systems thinking and a democratic process, involving users, was defined.

Both system engineering and human-centred design requires the identification of several potential solutions. Systems engineering mainly searches for solutions to improve concepts, while human-centred design focuses on solutions for improved user-experience. The study aims to cover both aspects on solution design and additionally, to consider system-of-systems objectives. To allow for all three aspects, the study has suggested to apply a socio-technical perspective, including system-of-systems architectural principles, to the future VTS.</td></tr>
<tr><td><i>Which approach can support design of the future VTS?</i>
a) How can a socio-technical systems approach focusing on a democratic process, and</td><td>Review of literature:
Socio-technical systems theory, system-of-systems theory and participatory design</td><td>Paper: “A socio-technical perspective on the future Vessel Traffic Services” in Necesse (2019)

Presentation at Human Factors in Control Conference, Trondheim, October 2019</td></tr>
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<tr><td>systemic evaluation of internal and external consequences, be used in the early design phase of the future VTS?</td><td></td><td></td></tr>
<tr><td colspan="3"><u>Stage 4: Descriptive Study II</u>
The final stage of the study explored one of the four aspects of system-of-systems architectural principles in the suggested socio-technical perspective. By evaluating if the VTS can facilitate for coexistence, the study both considered the role of the VTS and if the complementary mindset is useful in the early phase of designing new concepts. A prototype of a future Maritime Traffic System was developed to allow for evaluating if the changes create a safe coexistence that would not have been present without the introduced changes.</td></tr>
<tr><td><i>Can the Vessel Traffic Services facilitate safe coexistence in the future maritime system?</i>

a) Can the future VTS apply traffic organisation and traffic regulation measures to facilitate for safe coexistence between conventional and autonomous vessels?</td><td>Workshop with subject matter experts to identify future traffic system

Simulation of future traffic scenario

User-involved design process of the future VTS</td><td>Paper: “The Vessel Traffic Services contribution for safe coexistence between automated and conventional vessels”</td></tr>
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5.3 Research methods

Review of literature. In research question 1-3, a review of literature has been used. The search has been primarily done in Oria and in Google Scholar. The search strategy has followed the research process and the research questions, starting with broad keywords, and later being narrowed down to more precise keywords in phrased search and in combined search. Examples of broad keywords used in the literature review are *autonomy*, *responsibility*, *control, complexity,* and *systems*. Phrased search has been used for terms like *“maritime traffic systems”, “sea traffic systems”* and “*socio-technical systems”.* While combined search has been used for terms like *“socio-technical systems”* + *maritime*, and for combined phrased search such as *“maritime navigation”* + *“governmental responsibility”.* The literature review has been included in a review form with database, phrases used, hits and relevance.

A structured literature review is useful for a broad understanding of the research area. When deciding the keywords in advance, I soon discovered which theories and methods were relevant to my study. On the other hand, most of the literature is found by following discussions in journals, where one concept is linked to another concept, and my interest on what to pursue has been the most important driver. All articles found relevant have been downloaded, and I have used the search function in the reference tool to compare different terms. For the broadest terms, this method has been quite useful. As an example, a search for the term *complexity* gives millions of hits on Oria, while it leads to a couple of hundred hits in my downloaded papers.

Data collection. Gathering data from users has been central for the thesis. The data collection was performed in Norway through a field study of a VTS, simulations of future maritime traffic systems with Traffic Separation Schemes, and a user-involved design process of the future VTS.

Field study at Vessel Traffic Services

A field study of the Norwegian VTS, Kvitsøy VTS, was carried out in October 2018. The aim was to perform a cognitive task analysis of VTS operators when assisting vessels in all phases of the voyage in the VTS area, from entering area to port. The study was planned in cooperation with the Norwegian Coastal Administration (NCA) who suggested to study Kvitsøy as this has the highest traffic volume of the Norwegian VTS'. NCA made all relevant VTS procedures available and these were reviewed prior to the field study. The actual site visit was performed 23-25th October 2018 where all 7 VTS operators on duty during these days were interviewed. This represents 50% of the VTS operators employed at Kvitsøy VTS. A question set based on combining the Applied Cognitive Task Analysis (ACTA) and Critical Decision Making (CDM) was applied to get data on both routine and critical events.

Simulation of a future traffic system with Traffic Separation Schemes (TSS)

In 2019 I supervised a master's study on the use of simulators for decision-making. The master students and I had overlapping interests in collecting data from end-users to describe how autonomy could affect a maritime traffic system in 2025. Additionally, it was useful for my study to learn more about how to measure safety and efficiency effects in a simulator.

The use of TSS falls under the responsibility of the NCA and we invited the NCA to scope and planning the study. In addition to the planning meetings with the NCA, three sessions were arranged:

1) Scoping a future maritime traffic system
   In February 2019, we held a workshop to describe a future maritime traffic system. The workshop was assigned two tasks. One to describe the typical traffic picture, including a concept with autonomy. The other to use TSS to design a traffic system. The geographical area used is one of the test areas for autonomy; Storfjorden on the northwest coast of Norway. To cover different perspectives, eight users with the following experience participated: leisure boat captain, navigator on the ferry crossing in the area, rescue boat captain, lecturers from NTNU holding a deck certificate, a legal expert from the NCA, and the person responsible for traffic regulation at the NCA.
2) Validating the scenario
   After the results from the initial workshop were programmed into the simulator, the participants were invited to validate the scenario. Two traffic situations in different geographical areas within the test area were presented to the participants. In addition, a test run of the simulator study was performed by using bachelor students to man the simulator bridges.
3) Simulator study
   The simulator study aimed to identify safety and efficiency effects of TSS in a future maritime traffic system. Eight navigators with no prior knowledge of the study participated. The navigators were divided in two groups. In each group the four navigators manned one bridge each and were exposed to one scenario with TSS and another scenario without TSS. Safety and efficiency were measured qualitatively; stress level using an Individual Stress Assessment-method (ISA), expert group assessment of the situation, and the participants self-assessment on a survey after the simulation. Data from the simulation were used for a quantitative assessment of efficiency through speed and distance sailed, and safety through Closest Point of Approach (CPA) and use of dynamic safety zones.

User-involved design process of the future VTS

In the last quarter in 2019, a user-involved design process of the future VTS in cooperation with NCA was carried out. The research was integrated with an NCA project to assess and utilise the potential of digitalisation for the VTS. The purpose of the design process was to explore how the VTS can facilitate for a safe coexistence between conventional and automated vessels by traffic organisation and traffic regulation. The data collection was carried out in two workshops in November and December 2019, where the VTS managers from all five VTS' participated together with one or two VTS operators from each site. In addition, three representatives from the NCA management participated. In total 14 participated in the first workshop, and 12 participated in the second workshop. The data was collected as a combination of focus groups and plenary discussions.

The participants were divided into two groups and in the first workshop they discussed challenges for today's VTS in a future MTS, and how traffic regulation and organisation measures can be used in the traffic scenarios developed in the abovementioned simulator study. In the second workshop, the participants were presented a prototype of an MTS based on their input from the first workshop. Subsequently, they discussed if the prototype reflected their statements from the first workshop and what should be changed. Further, they discussed the likelihood and challenges of implementing the measures for the VTS.

5.4 Reliability and validity

The term reliability and validity origin from quantitative research and needs to be interpreted in a qualitative context. Consequently, the reliability and validity are discussed, but are linked to terms appropriate for qualitative research.

5.4.1 Reliability

Wilson and Sharples (2015) uses auditability, consistency and dependability as alternative terms for reliability. The relevant reliability terms relevant for this study is auditability and dependability.

Auditability. The role and status of the researcher is an important aspect of auditability. The significance values in the research is discussed in detail in chapter 4.2 *The role of values in my project.* The reason for discussing this separate to the reliability and validity section, is the link to the epistemological discussion in chapter 4.1 *Ontological and epistemological stance of my research.*

The overall challenge for the auditability is to know how to use my personal background to support my research by finding a research approach that provides a good contribution, without allowing my background to affect the research illegitimately. This challenge was most apparent in the last research phase. When introducing the project to the workshop participants, I had to balance between presenting concepts and ideas from aviation to inspire the participants to think outside the box on the one hand, and the risk of making the participants confirm my own ideas on the other. This challenge was discussed with supervisors and fellow researchers prior to the workshop, and the values are argued to be playing a legitimate role by:

1. Knowing the workshop participants are experienced personnel who we expect can evaluate suggestions rather than confirm them.
2. Clearly stating the stance of the research and the expectation to participants to consider the suggestions as inspiration, not solutions.
3. Avoiding affecting the discussion, and by handing out written instructions to the focus groups that allowed the participants to facilitate the discussion themselves.
4. Revisiting the suggestions after the data collection to see how many of these ended up as solutions. When the results showed that some suggestions were used as inspiration, while many where not taken further, it is concluded that the groups had an open discussion rather than confirming my ideas.

Dependability. Fishman (1999) describes dependability as establishing a process of a study so that it can be documented and reconstructed. This study considers a future situation where autonomy is introduced. What this future will look like is uncertain, the term autonomy is ambiguous, and the direction of development is contested. Doing research about such uncertain future requires a strict framework that addresses the right things and documents the choices of direction.

The study has used a research approach developed by a dedicated Design Research Methodology (DRM) and connected to a convergent process that includes both systems engineering (SE) and human-centred design (HCD). As such, the process is considered to be possible to reconstruct. However, a weakness is experienced in the process of iteration and interaction. Iterations are emphasised in both DRM, SE and HCD, but when to iterate is not defined and consequently, iterations are to a lesser extent documented in this study. The strength of the study is the close cooperation with the NCA and the opportunity to present in different forums that has given valuable input and a natural iteration.

A similar challenge is experienced regarding when to switch between systems thinking and design thinking. There is little guidance regarding when to shift perspective between these two approaches, and therefore I had to estimate when to switch, which could be seen as subjective. However, I have distinguished between perspectives in the two stages of the project where it is relevant; Descriptive Study I and the Prescriptive Study.

5.4.2 Validity

The validity of the study is discussed by internal and external validity. In qualitative research, validity is closer related to the soundness of arguments than truthfulness of statements or analysis (Lützhöft, Nyce, and Petersen 2010). To discuss internal validity, credibility is highlighted. External validity is discussed by transferability.

Credibility. Credibility is to create an isomorphism between the perspectives of the participants and my reconstruction (Fishman 1999) and relates to the hermeneutical tradition of having a dialogic process with the participants. To increase the credibility, a respondent validation by presenting the researcher’s interpretation or triangulating, by using more than one method, data source or investigator, can be carried out (Wilson and Sharples 2015). The credibility of the study has been strengthened primarily by representing my interpretation to the participants. The scenarios for the simulation were visualised in the simulator, and the interpretations of the data in the user-involved design process were presented as a ‘day in an automated vessel’s life’. As such, visualisation and story-telling have been important measures for credibility as it brings the context to the interpretations. This has been useful for clarifications and to identify misinterpretations.

Another contribution to credibility is giving the same task to two groups. This was done to identify scenarios and in the user-involved design process. After each group session, a plenary discussion was facilitated and contradictions between the groups were discussed. In most cases contradictions were related to the context and not to the opinions on solutions. E.g., most of the contradictions in the user-centred design process were related to which situations that should be covered, not which responses the VTS should have to a situation.

In the second stage of the study, the field study at Kvitsøy VTS, two different cognitive task analysis methods were used, and these provided a set of questions asked to all participants. The results were presented to the NCA, however, I did not present the interpretation of the data back to the actual participants in the study, which could be challenging the credibility.

Transferability. Transferability is the applicability to other sites and providing a ‘thick’ description to be used for generalisation (Fishman 1999). In a qualitative study, the findings are closely related to a context. To be able to know what is useful to others, the results and the context must be detailed. One of the main motivations for the study is the dual perspective of systems and humans. Such a dual focus enforces the discussion between the general issues and in-depth, context-dependent discussions. The context-dependent situations in the study are the data collection at Kvitsøy VTS and the user-involved design process. Both studies use a non-probabilistic sampling, and a bias in selecting participants can negatively affect the transferability. Particularly for the user-involved design process, this can be a weakness of the study. The study requested the VTS managers to participate together with an experienced VTS operator, preferably a VTS instructor. On the one hand this can challenge the transferability. On the other hand, this was weighed against the benefits of having experienced operators that would increase the auditability as discusses earlier in this section. The transferability of the study is considered to be strengthened by including operators from all VTS' in Norway, including the VTS management. A corollary of focusing on the VTS is to use personnel from the VTS organisation in the data collection. Inviting other actors, such as navigators or pilots, could have contributed to a richer data set. However, as this study reflects an early design phase, I have considered it more relevant to focus on the VTS personnel.

In the last stage of the study, it is important to emphasise the scope and the boundaries for the study. This scope and boundaries can potentially affect the transferability since the study discussed a 2025 scenario with an *automated* vessel, i.e. not an 'intelligent' autonomous vessel. As being discussed in the first stage of the project, I consider high-automation solutions to fall under the autonomy description and I emphasised this to the participants of the user-involved design study. By framing the scope, I was able to describe the context and develop a prototype of the 2025-scenario. However, the results from the study are closely related to the limitations in the scope and the 2025-scenario. As such, the transferability of the findings cannot be guaranteed. To reduce this uncertainty the findings must be replicated and tested in other scenarios. However, as many of the discussions in this stage of the study are related to more general challenges of traffic management, I consider the study to have a solid transferability potential.

6 Results and discussion - a systems perspective on maritime autonomy

The results and discussion chapter follows the four stages in the research approach presented in 5.2.

Chapter 6.1 represents the Research Clarification phase, and the title 'Humans a part of autonomy' refers to the motivation and the stance of the research.

Chapter 6.2 'The Vessel Traffic Services' role in the maritime system' refers to the stage Descriptive Study I, where both a system and a human-centred perspective describe the existing situation.

Chapter 6.3 refers to the Prescriptive Study where 'a socio-technical systems approach to the future VTS' suggests focusing on a democratic process and systemic evaluation of internal and external consequences in the early design phase.

Finally, chapter 6.4 refers to the Descriptive Study II, exploring 'the Vessel Traffic Services facilitating for safe coexistence in the future maritime system'.

6.1 Humans a part of autonomy

"Autonomous shipping is the future of the maritime industry. As disruptive as the smartphone, the smart ship will revolutionise the landscape of ship design and operations"

Mikael Mäkinen, President, Rolls-Royce Marine (Rolls-Royce, 2016)

This statement from Mäkinen describes a quite common belief in the maritime industry, that autonomy will be rapidly developed and implemented. He foresees a development of autonomous shipping where smart ships are disruptive, indicating that the role of autonomy will be something different than the previous development of shipping. Predominant motivations for introducing autonomy are increased profit through increased productivity or reduced costs and safety improvements by moving humans from operations traditionally associated with high risk. It is also believed that the availability of skilled seafarers will diminish due to the decreased attractiveness of seafaring profession, and therefore autonomy would be necessary (Munin 2016). The expectations on autonomy are many, but to evaluate such claims we have to start to look at what autonomy is.

6.1.1 What is autonomy?

The term autonomy has been used since the early 17th century and is explained as the right or condition of self-government, as the freedom from external control or influence, and being independent (English Oxford Living Dictionaries n.d.). The independence and self-government aspect of autonomy has mainly been used in healthcare to describe the patient's role in deciding their treatment. However, we could use autonomy, or independence and self-government, to describe the maritime industry. During the Age of Enlightenment, explorers like Columbus discovered the world outside Europe. These explorers had no communication with their principals, who paid for the expeditions, for months or even years. To claim that Columbus was independent and self-governed, at least during operations, is not disputable. Further, the claim could be tested for modern shipping. During the last century, ships are still operating remotely from the rest of the organisation with limited support from shore-based services. Even with continuously better connectivity improves the cooperation between ship and shore, ships are still to a large extent self-governed and independent and could in some form fall under the autonomous term.

Mäkinen's statement is not about autonomous aspects in traditional shipping. He refers to a *disruptive* future within shipping and compares it to the development of smart phones that we know have changed much of our lifestyle. Mäkinen's statement is in line with the general discussion of autonomy that is initiated and driven by technology development and particularly, the development within digitalisation. Some of the relevant digitalisation trends for the coming decade are (DNV GL 2020):

- More connection to the internet

- Ubiquitous sensors (Internet of Things - IoT)
- Communication and computing everywhere
- Artificial intelligence
- Platform-based social and economic models
- The digitisation of material through additive manufacturing

Concluding that the discussion of autonomy is initiated and driven by technology development is undisputable. Digitalisation will change our society in general and change the maritime industry more specifically. Autonomy is intended to be something different than the shipping we know from today; autonomy relates to the technology development, and particularly how digitalisation, can change the involvement of humans in maritime operations. Since technology development has significantly affected our society the last hundred years, it is reasonable to reflect on what is new about autonomy and why do we need this new term?

Automation and autonomy. Technology development affects how humans work, and the use of more advanced technology is the fundament in socio-technical systems and human-technology interaction. These systems and interactions consider that the quality of working life and democratic processes to humanise the workplace were the foundation to use and accept technology (Trist 1981). A significant change to the human-technology interaction is automation, where technology takes over functions previously carried out by humans (Parasuraman and Riley 1997), and since the 1980s the use of automation has accelerated and reduced the need for people to be directly involved in operations (Mumford 2006).

Automation brings with it benefits and challenges, and my intention is not to scope out all of these, but the most conspicuous benefits are moving humans away from direct involvement of dangerous tasks, making processes more efficient and reducing costs. On the other side automation challenges is experienced when exceeding the limits of what the technology can do, and humans are put in the role to supervise and potentially take over when technology fails. The *irony of automation* describes the challenge of keeping the humans out of the loop since technology is superior to humans, while asking the humans to take over when technology fails (Bainbridge 1983). Additionally, *automation surprise* describes when technology acts in an unexpected way for the human operator and potentially creates dangerous situations (Sarter and Woods 1997).

As for autonomy, technology development is an important driver for automation and makes differences between the autonomy and automation hard to pinpoint. In colloquial language use it is difficult to see any distinctions between the two terms and they are used interchangeably. In Parasuraman's (2000) version of Level of Automation, the highest level of automation is when the computer decides everything and acting autonomously, indicating that autonomy is the ultimate use of automation. One apparent challenge of understanding autonomy as when everything is automated, is that it is too narrow for describing the disruptive future where digitalisation is applied in new ways and create new solutions.

The Society of Automated Engineers (SAE) has decided to label *autonomy* a deprecated term. The reason is twofold. One is that *autonomy* has become synonymous to *automated* when including system functionality and not only decision making. The other is that autonomy relies on algorithms and command of users and consequently is not self-governing (SAE International 2016). One option for the maritime industry is to follow the car industry and SAE – to leave the term autonomy or to use autonomy about the highest level of automation. On the other hand, the term is commonly used in maritime industry about a disruptive development, as described by Mäkinen, indicating that autonomy is something different than automation.

The challenge for maritime industry is the frequent use of the term autonomy with different interpretations, and this creates an ambiguity of what autonomy really is. To overcome this challenge, it is necessary to relate autonomy to automation and to understand both similarities and differences between the two.

Describing autonomy. In 'A Human Perspective on Maritime Autonomy' (Relling et al. 2018) we discuss the automation and autonomy terms and some of the criticism of using *levels* in combination with both terms. To find one concrete definition of autonomy falls outside of the scope of the paper. However, we claim that the following statements are useful for the autonomy discussion:

- Autonomy is not the goal itself, the objective of autonomy is to improve a system's performance
- Autonomy is a process of change rather than a state of being
- Digitalisation is the main component in the change process
- Autonomy aims to reduce human presence in dangerous and hostile environments
- Autonomy implies a significant change to the system where emergent properties are expected to affect the overall system's performance

The most controversial statement is probably that autonomy is a process and not a state of being. The rationale for the statement originates from asking how autonomy can be a state of being, and there are two main arguments against this. One follows the SAE argument problematising the self-governing aspect of autonomous entities. All human-made systems are designed for a reason, and such reasons are linked back to benefit the humans. Consequently, humans will continue to manage the system to perform to our best. As such, the self-governance is not achievable nor desirable, and to design a system that is being autonomous should not be the objective. The other main argument is, even if we ignore the abovementioned challenge of self-governance, an autonomy state of being where technology copes with all situations in an operation is, at least at present, a utopian idea. This is not to reject that technology could cope with a dynamic and complex future. However, to limit autonomy to be only about such state of being would not reflect the on-going discussions of development in the transport section. The on-going discussion concerns the human-technology interaction and responsibility in a dynamic environment and relates to the same challenge experienced in automation, that technology not simply replacing human activity, but rather changes it (Parasuraman, Sheridan, and Wickens 2000).

Consequently, we suggest considering autonomy as being the process of utilising technology and optimising the human-technology interaction in a system. As such, autonomy being a process, could be different from system to system and from segment to segment as the change process could face different requirements and challenges. A corollary to claiming autonomy being a process rather than a state of being, is that a system never can *be* autonomous, such as an autonomous vessel or an autonomous car. An apparent challenge is to how to label a vessel when the process of digitalisation that has led to significant changes, is concluded. One solution could be to label the vessel with the result of the process. The IMO's (2018) description of degrees of autonomy is partly in line with labelling autonomy as the result of a process by calling it *ships with automated processes and decision support* and *remotely controlled ships with or without seafarers onboard*. However, the IMO's final step is *fully autonomous ship*, hence relating autonomy to a state of being, and falls outside understanding autonomy as a process.

What is autonomy? The answer to the research question of what autonomy is, is not a definition of autonomy. Rather it is an understanding of how autonomy relates to automation, about if and how it can be described in levels or degrees, and if it is considered as a state of being or a process. In my study, I consider autonomy to be a process rather than a state of being and in short term I consider autonomy to be the process of utilising digitalisation to increase the system performance.

To be precise on explaining autonomy is a larger challenge than expected, and apparently one core autonomy challenge. There is much ambiguity to the term autonomy. In the early phase of the development one could accept ambiguity on the term autonomy, however, as the development progresses the use of the term should be clarified. If agreeing on using autonomy for the *process*, it is necessary to find suitable labels for the result of the process. A consensus of autonomy is *a state of being*, makes it is necessary to define what needs to be fulfilled to reach this state of being. Additionally, it must be considered how to relate to concepts capable of being in many different states during operations. As an example, if a vessel shifts between the degrees of autonomy as IMO describes, is it continually an autonomous vessel throughout the operation, or is it an autonomous vessel only when it operates as a fully autonomous vessel?

One way to describe the similarities and differences between autonomy and automation is to visualise the overlap. Figure 10 shows automation as spanning from low-automated systems, where a simple exchange of some tasks from human to technology is experienced, to highly-automated systems where technology is used more extensively. Autonomy is imagined overlapping with high-automation, but further, extends further to be more than automation.

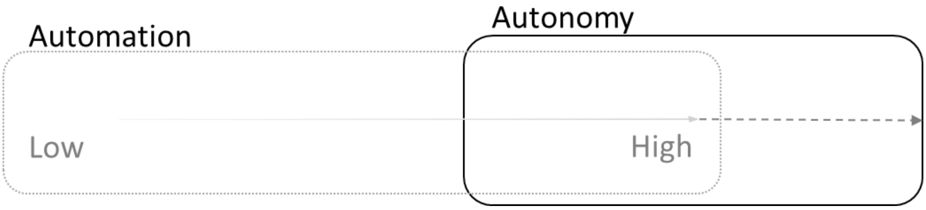


Figure 10: Automation and autonomy are partly overlapping terms. Automation spans from low-automation to high-automation, while autonomy could overlap with high-automation, but also utilise digitalisation in ways outside what is seen in high-automated solutions.

The rationale for expanding autonomy outside high-automation is to include new and different use of technologies. The most apparent use of new technology is a wider use of artificial intelligence that in my perspective, relates to autonomy rather than automation.

In sum, I consider autonomy as a process, however I have throughout the project been disloyal to my own consideration and used autonomy as a state of being in several discussions. Particularly, to communicate about autonomy is easier when linked to a state of being, the term "*autonomous vessel"* immediately gives people associations that the term "*autonomy as a process"* cannot give. My disloyalty could be found in the goal of safe coexistence between conventional and autonomous vessels, and underlines that no good alternative for replacing the term autonomy with a different term is yet in place.

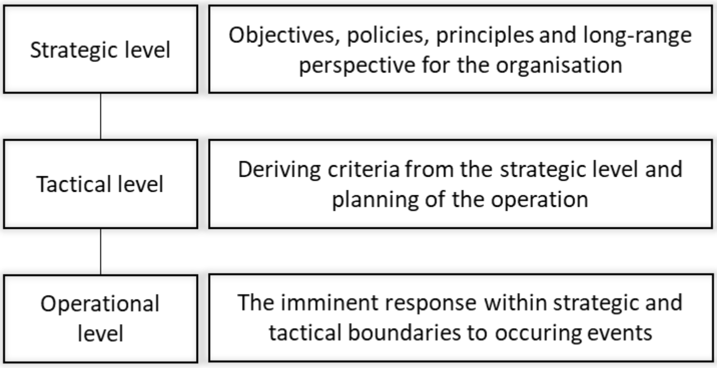
6.1.2 How to adopt a systemic human-technology approach in maritime autonomy?

A motivation for the study has been to balance the technology focus in maritime autonomy, and in our paper 'A Human Perspective on Maritime Autonomy' (Relling et al. 2018) we discuss how humans will be in the loop in in future maritime systems, but there will probably be new loops. We limited our focus to consequences for safety in the navigation function.

Humans will strengthen the system. Autonomy is considered to cause significant changes to the maritime system. Future maritime systems are expected to have more components and interactions, consequently having a potential of becoming less predictable and more complex than present maritime systems. Keeping the systems safe is a constant objective between present and the future. A frequently used statement of safety level is that changes caused by autonomy should result in systems as safe, or safer, than present. A consequence of taking a systems perspective, is that safety cannot be understood in isolated components of the system. Safety is created by the interaction of system components, and safety is therefore an emergent property of a complex system (Leveson 2004). When safety cannot be understood by the components in isolation, a different approach than the traditional reductionistic safety thinking is needed. One approach is to use the resilience term, where safety is maintaining a stable system performance in a changing environment: The system needs to respond to a changing environment, and in complex socio-technical systems, it is currently the human's performance variability which is a prerequisite for functioning systems (Hollnagel 2012a). The human ability to interpret and adapt to shifting demands is superior to technology. On the other hand, humans make mistakes and the term human error are often used as an explanation of accidents. What the term ignores, is all the occasions when humans save the day and counter for inadequate technology. It is therefore necessary to be wary about the belief that autonomy is only about introducing more technology, and that this is coherent to a reduction of human error.

There is no reason to ignore how humans have strengthened systems in the past. Future systems should utilise these strengths that are best evident in a systems perspective. When we see how humans contribute to keeping a system stable in a shifting environment, we can implement these strengths in future system. If we do not take the whole system into consideration, we could end up in a situation where safety is assessed by technical components or isolated processes. This could lead to an incorrect conclusion that systems are as safe, or safer, while new risks that emerge in new human and technology interaction are ignored.

Humans in new loops but being responsible. Maritime autonomy is expected to cause significant changes to the maritime systems. In a historical perspective, ship and shore have never been more connected than at present and this connection needs to be considered. To better understand the expected changes of autonomy, it is useful to take an organisational perspective and discuss maritime specific challenges on a strategic, tactical, and operational level. Figure 11 shows the connections between the three levels. The literature does not concur on the order of the tactical and operational level, but the labelling of the levels is subordinate for this discussion.



Strategic level	Objectives, policies, principles and long-range perspective for the organisation
Tactical level	Deriving criteria from the strategic level and planning of the operation
Operational level	The imminent response within strategic and tactical boundaries to occuring events

Figure 11: The various organisations levels will be affected differently by autonomy.

The changes caused by autonomy are mainly expected to be on the operational level, to a lesser degree on the tactical level, and no changes are expected on the strategic level. The rationale for this expectation is the ability to perform trade-offs between overall objectives, where humans are superior to technology (Hollnagel 2012a). Consequently, the expected changes by autonomy will primarily be experienced on the operational level.

Even though not always expressed, maritime autonomy is to large extent about a change in the role of the master. Any change in the master's role is a drastic change and would be a paradigm shift in the industry. A key element in this paradigm shift is how to cover the master's responsibility. Both internal responsibilities of the state of the vessel, and external responsibilities towards other vessels need to be covered. These responsibilities are described in formal tasks but are also to a large extent composed of informal tasks. Autonomy could result in some of these responsibilities to disappear, while other might be added. However, by and large the responsibilities are a constant that cannot be ignored, and the perspective of the authorities is that the overall responsibility for top-functions, such as navigation, will, at least in the near future, remain with the humans.

The model in Figure 12 visualises the relationship between responsibility, control, and authority. In a future maritime system, where the humans are responsible for the top-functions they might allocate authority of decision-making and execution to technology. If the responsible is on shore and the executor is on the vessel, the importance of control increases. Control is described as the allocation of constraints and tasks to the executor and the feedback of information of system status, rationale for decisions, and the actual decisions made, back to the human being responsible.

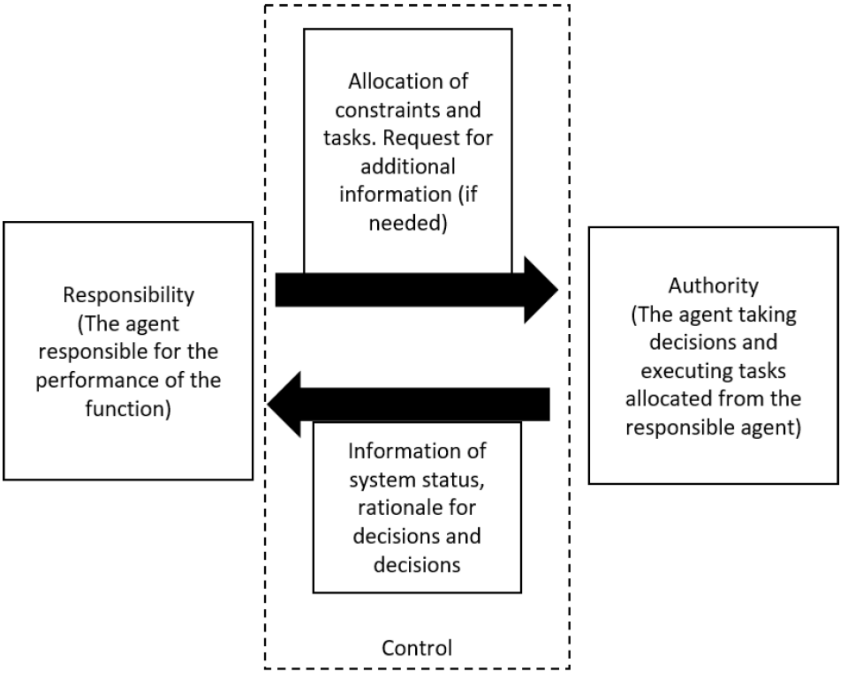


Figure 12: Control links the responsibility and authority

An important aspect of the model is that the only static element is the responsible aspect. Who is given authority to execute, and how to remain control, will change based on the context. As such, when considering autonomy, it is important to have sufficient variability, or being sufficiently dynamic, to cope with a shifting context.

A systemic human-technology interaction. The reason for considering systemic human-technology interaction is two-fold. One is raising the *awareness* to include human-technology interaction in designing future maritime systems. The other is understanding *how* to consider a systemic human-technology interaction.

The need for an awareness of human-technology interaction origins from the present technology focus in maritime autonomy. This needs to be balanced with an understanding of humans being an important part of future systems. The ability to adjust performance to keep systems stable will continue to be significant and even more important when autonomy makes system more complex. The human performance variability is a strength maritime autonomy cannot afford to ignore in such complex systems.

The study has highlighted moving the master from the bridge to a shore-based location as a central challenge in maritime autonomy. Despite being a new situation, the responsibility is a constant factor, and the responsibility for top-functions, such as navigation, needs to be assigned to someone. At least in the near future, this someone is a human. As such, we need to consider how the humans remain responsible while tasks are being executed on the vessel. Control, to link responsibility and authority, is suggested as a term to understand the human-technology interaction in future systems. Particularly, how control needs to encounter for a dynamic context, has been presented as a central design challenge.

6.2 The Vessel Traffic Services' role in the maritime system

The thesis explores how the future VTS can contribute to safe coexistence between autonomous and conventional vessels. To discuss the future VTS requirements, it is necessary to understand the role of the existing VTS. In the following chapter, the first section describes the role of the VTS by a system thinking approach and the second section by applying a design thinking approach.

The systems thinking approach explores how the VTS contributes to the maritime traffic system by relating the VTS to the larger maritime traffic system. The design thinking considers how the VTS operators use expert knowledge and strategies in the interaction with vessels.

6.2.1 How do the Vessel Traffic Services contribute to the maritime traffic system?

The fundamental principle in systems theory is to consider the whole rather than parts, and reason is that studying single part or processes will not explain vital phenomena (Bertalanffy 1929). Applying this fundamental principle to the VTS, as the system of interest, argues for understanding the VTS in a relation to other systems. To consider the whole including these relationships, the VTS is discussed under the three aspects of systems theory described by Bertalanffy (1972) and presented in chapter 3.1: systems science, systems technology and systems philosophy. The VTS has been described as *a complex socio-technical control system in the maritime traffic system* (Nuutinen, Savioja, and Sonninen 2007; Praetorius and Hollnagel 2014). The following paragraphs discuss different elements of this statement to find relationships for, and properties of, the Vessel Traffic System.

The VTS and systems philosophy. The principle of considering the whole opens for considering the VTS in a larger perspective; to know more about the relationships to other systems and to know more about the larger whole the VTS is part of. The ontological question of what a system is, points to a difference between what the VTS is and what the larger whole is. The VTS is a system that could be described as ontologically objective, or in Miller's (1965) term, a concrete system or in Bertalanffy's (1972) description, a social system. The VTS can be defined and described in an unambiguous manner. However, to describe the larger whole that the VTS is a part of is more challenging. To be a control system in the maritime traffic system is a description of a larger whole as a maritime traffic system, hence, the first step is to answer the ontological question of what such a maritime traffic system is.

The maritime traffic system (MTS) is, as opposed to the VTS, not a concrete system. The MTS is an ontologically subjective system, or in Miller's term an abstracted system where the relationships are abstracted by an observer. Consequently, the MTS is a context-dependent system, that changes from one geographical location to another and changes over time (Relling, Praetorius, and Hareide 2019). In my study, the focus on safe coexistence has led to identifying stakeholders that affect or are affected by the achievement of safe navigation and stakeholders have been defined as the one involved in the immediate relationship between the operators on the VTS and operators of vessels within the defined geographical area (Relling et al. 2019).

The VTS and systems science. The principles of general systems theory to apply the 'wholeness' and interactions is central to the systems science and a variety of system-theoretical approaches are suggested. Praetorius (2014) describes the VTS as a control system, where control is related to resilience engineering, and the ability to maintain a stable output in a changing environment. This underlines that the VTS is an open system that interacts with the environment. The relationship with the environment is the interaction with the vessels within the area, and even if the responsibility for navigation rests with the individual vessel, the role of the VTS is to contribute to stability, or safe coexistence, in the maritime traffic system.

The VTS and systems technology. Bertalanffy (1972) claims complexity in the technology and society is a systems technology aspect that requires a holistic and interdisciplinary approach. Complex or complexity is often used to describe the VTS (Nuutinen, Savioja, and Sonninen 2007; Praetorius and Hollnagel 2014), the tasks for the VTS (IALA 2016a; Praetorius et al. 2012; Praetorius, Hollnagel, and Dahlman 2015; IMO 1997), and the MTS as a system (Mansson, Lutzhoft, and Brooks 2017).

The wide use of complexity, and the difficulty to define the term, is acknowledged by Hollnagel (2012b) and Flach (2012). Hollnagel links complexity to when it is difficult or impossible to make predictions, while Flach discusses complexity in terms of problems with increasing number of possibilities. The coherence between the two perspectives is found in prediction; the more challenging it is to predict; the more complexity increases.

The degree of complexity for the VTS is intimately related to the shifting demands in the environment, or in the maritime traffic system. To maintain stability in such shifting demands, the attributes of the VTS need to change. The interplay between a control system and the environment is described in cybernetics, where Ashby (1956) uses requisite variety to explain that only variety in regulations can force down the variety due to disturbance. In our terminology, the VTS needs to have the same or larger variety in its attributes as the variety in requirements in the environment in order to contribute to stability, or a safe coexistence, in the maritime traffic system.

The VTS' role in the maritime traffic system. The system thinking approach by applying the three aspects Bertalanffy uses to describe systems theory describes the VTS role in the maritime traffic system (MTS). The VTS is a part of a larger whole, and the larger whole is framed as the MTS. Contrary to the VTS, the MTS is an abstracted system, and is context-dependent. The context for the study is safe coexistence, and the MTS is composed of the vessels in the defined geographical area and the VTS as the control system as visualised in Figure 13.

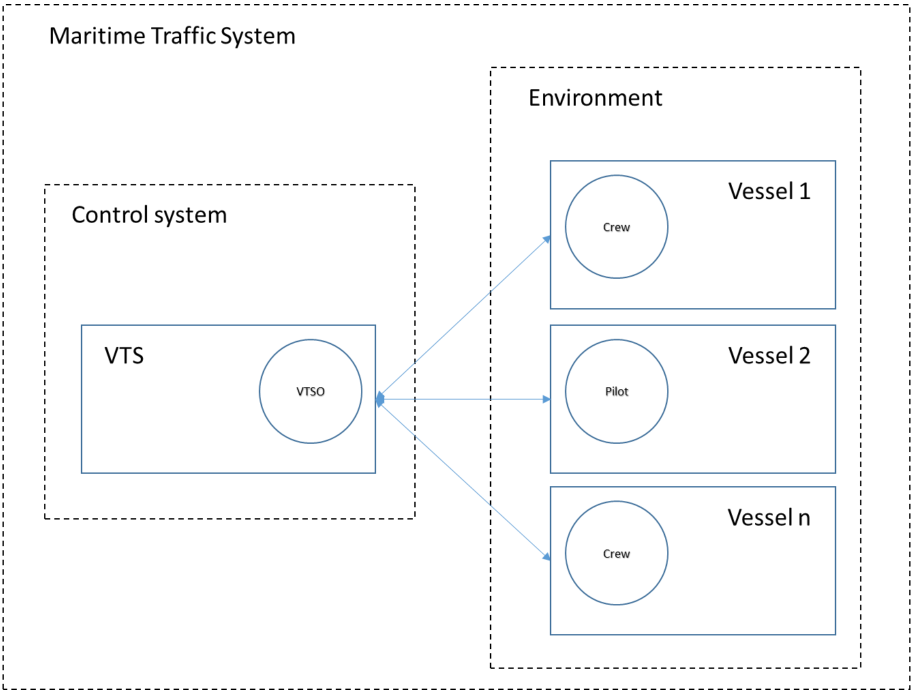


Figure 13: The Maritime Traffic System (MTS) is composed of the vessels in the area as the environment and the VTS as the control system

Being a control system points to a responsibility for stable performance in the MTS, and one important aspect of stable performance is safety. The challenge to stable performance is the complexity caused by both external and internal variations to the VTS. The external variations are the shifting demands of the environment, namely variations in the demands of the vessels in the area. The principle of requisite variety applied to the dynamics between the VTS and the environment underlines that the VTS need to have a variety of response that is equal to, or larger than, the variation of demands in the environment. Hollnagel and Woods (2005) claim that the requisite variety should be interpreted as an isomorphic performance based on functional adequacy, not structural similarity. As such, the requisite variety for the VTS will be achieved to functional adequacy through performance that meets the demands in the environment.

Hossain et al. (2020) emphasise that understanding the emerging of complex systems is one of the future challenges for systems engineering. One possible path to such understanding is using the dynamical systems theory and look for both an internal and external description of systems. The external description relates to the interaction between the VTS and the other component systems of the MTS and describing the requisite variety of the VTS. However, an internal description of how such variety is created is necessary and could provide a more better understanding of the VTS as a complex system.

At present, the most important measure of requisite variety through functional adequacy, is human performance variability. In the next chapter, I focus on how the VTS operator contributes to the requisite variety for the VTS by coping with the complexity in the environment.

6.2.2 How do VTS operators use expert knowledge and strategies in the interaction with vessels?

The previous chapter explained VTS in a systems approach, where the VTS is a control system which requires a variety in its performance to match the complexity of the environment. The external description focus in the systems approach considers the VTS as a black box that needs to have a property of a requisite variety. However, the approach does not explain how the most important contributor to the variety, the humans, contribute. Consequently, it is imperative to understand the internal description; human contribution to requisite variety on the VTS, specifically, the performance variability of the Vessel Traffic Services Operators (VTSO).

A field study to explore the performance variability of the VTSO has been carried out, and this chapter reflects an extract of the study, while a detailed description can be found in the paper '*How vessel traffic service operators cope with complexity – only human performance absorbs human performance*' (Relling et al. 2019).

The study defines two objectives:

1) identify how the VTS operators use their expert knowledge and strategies
2) examine if there are variations between operators in the interaction with the vessels

The study was performed at Kvitsøy VTS in October 2018. Kvitsøy VTS is the Norwegian VTS with highest traffic volume and was considered to provide the richest data set. By combining Applied Cognitive Task Analysis (ACTA) and Critical Decision Making (CDM), the study performs a Cognitive Task Analysis that includes both routine tasks and critical tasks.

The results from the study are discussed under four main areas: operator experience, teamwork, organisational knowledge, and communication. Under these areas the results initially show how operators use expert knowledge and strategies, and subsequently, the variations between the operators are presented.

Operator experience. The operators' experience, both nautical experience and experience as VTS operators, affects how they imagine the situation on the bridge and consequently, which information the crew needs. One operator expresses this as *'building a mental maritime picture'*. Even though all operators have different experience, this mental maritime picture is inevitably different from one operator to the next. All the operators point out how the experience as a VTS operator in the area empowers their ability to differentiate normal vessel performance from abnormal performance. This experience facilitates spotting situations earlier and interacting with the vessel at the right time.

The operator experience is related to variations between operators. Two examples of variations found in the study are the use of standard communication phrases, and at what time to call vessels who have not reported when entering the VTS area. In the discussions with the operators they relate the variations to their various nautical experience such as different ship types, rank, years of experience and which trade they have been a part of.

Teamwork. In Norwegian VTS', two operators are on duty and the shift rotation leads to different operators being teamed up from week to week. Even if the two operators are responsible for separate geographical areas, the cooperation between the two is important. One operator expresses this cooperation as *'learning tricks from each other'*. This was confirmed during the observation by discussions between the operators both prior to taking a decision and discussion of solutions after decisions were made.

One interesting aspect of the cooperation is that the operators consider it to be a strength that they have different areas of interest, such as some being more interested in technical developments, while others have their interest in concept development. The operators have the possibility to call for an extra operator if a situation becomes critical. This is a safety measure that makes it possible for the operators to handle both the critical situation and the normal traffic in the area.

Organisational knowledge. The organisational knowledge is describing how *procedures*, *equipment,* and *regulations* contribute to coping with the external demands, or the complexity, that the operators experience. *Procedures* are mainly issued centrally from the NCA, while the individual VTS is responsible for tailoring the procedures to local use. Most of the VTS procedures outline the operator's responsibility, but a few of the procedures explicitly state criteria for *when* to act or *how* to act. On the one hand, the operators are concurrent in stating that making too explicit operation criteria is neither possible nor expedient due to the variations in the situations. On the other hand, the operators are positive to the few procedures that have explicit criteria, as they are easy to follow. A procedure giving the operators the authority to order a tug in any situation they feel is necessary, is considered as particularly helpful. In line with the possibility of calling an extra operator, the tug ordering procedure is an important safety measure in critical situations.

Some of the variation between operators can be linked to the procedures. As few procedures have explicitly defined criteria, it is up to the individual operator to choose how to solve situations and opens for variations between operators. However, the operators feel that it is difficult to develop procedures with more distinct criteria due to large external variations in the situations.

The important *equipment* for the operator is arranged in a workstation as shown in Figure 14. The functionality of the workstation affects how the operators cope. The systems on the workstation are under constant improvement, and in particular, more functionalities are added to the C-scope.

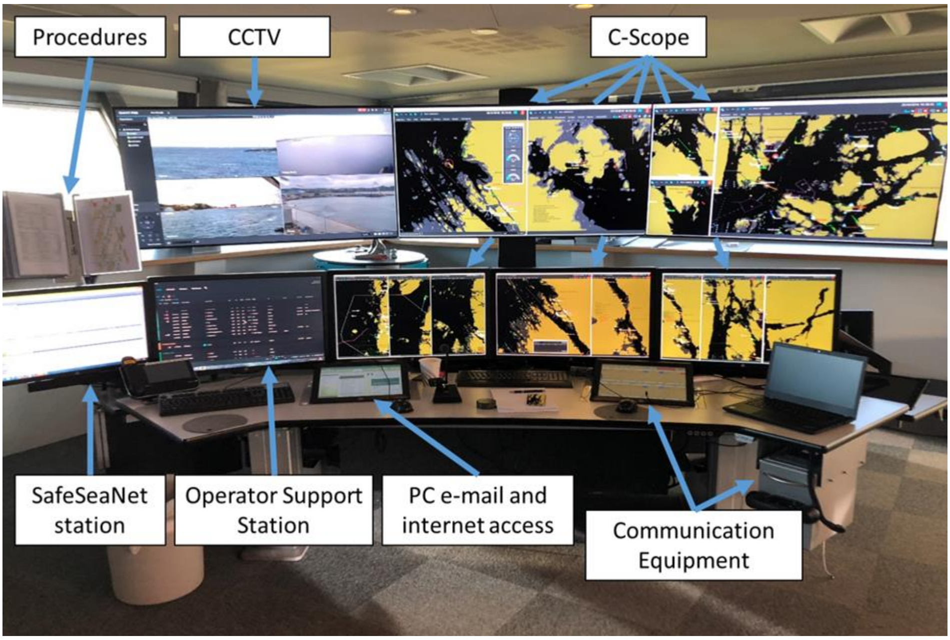


Figure 14: The VTS operator's workstation

The system constantly gains more and better functionalities in supporting the operator in monitoring and alerting the operators of abnormal situations. Alerts if vessels at anchor are drifting, is one example where use of alarms is an important aid for the operators. The challenge of using alarms is finding the right alarm levels where false alarms are avoided. Other important functionalities are tagging of vessels requiring special attention and marking of vessels with towing capabilities. The constant development of new functionalities is interesting and could be a driver for major changes for the VTS. As one operator states *'with the increased functionality of the workstation it could be possible to monitor a larger geographical area in the future'*.

The constant development of functionalities also entails some challenges. As discussed under teamwork, operators have different areas of interest. Some are more interested in technological development, and consequently more interested in using new functionalities while others are more reluctant. This creates variations in how much and when the functionalities are used.

The *regulations* of traffic affect the operator's performance. Regulations include traffic separation schemes (TSS), restriction in the use of fairways, and limitations during reduced visibility. The use of TSS provides a significant increase in the predictability of traffic situations for the VTS operators. This observation is interesting as it relates to the link between predictability and complexity. As such, when the TSS increases predictability, it could be said to be reducing the complexity for the operators, and this is seen when the operators say it creates an efficient traffic flow. The TSS is also a positive contributor for crews in communicating their intentions.

Passage restrictions is an efficient and frequently used restriction of the fairways. However, on the one hand, the restriction is positive, since it prevents traffic meeting in narrow waters, on the other hand, the VTS operators need to account for factors such as vessel type, weather and the local knowledge of the crew when organising the traffic.

Some variations between operators were observed, but since the situations were not necessarily comparable it is not concluded if the variations are due to the operators or the situations.

Communication. Radio communication on VHF is the primary communication between the VTS operator and the vessel crew. The radio communication is not only important because of *what* is being communicated, it is also important in *how* it is communicated. The VTS operators listen for indications of the crew not understanding what is being communicated. They provide a wide range of examples of situations where the vessel crew said they had control while the reality turned out to be different. The VTS operators say they are becoming more aware of the importance and get better at listening for such discrepancies as they gain more experience.

The VTS operators say that there are large variations between the operators in how they communicate. This variation is both about *when* and *what* is communicated. It is interesting to see that all the operators refer to the importance of using IMO's standardised communication even though it is rarely used. The operators use terms as '*assertiveness'* and '*short, concise and* '*correct'*, to describe how the communication should be. One contributing factor to not using standard communication can be that most of the communication is in Norwegian. Even for communication with vessels with English speaking officers, the communication is in English only until the pilot takes over the communication. The VTS operators provide examples of using Norwegian language having resulted in other vessels in the area not understanding the situation, and they see this as safety risk.

Communication is an important contributor to how the VTS operators cope, but how and when to communicate depends on the individual operator's discretion. The tool for reducing the variation is using standardised communication but seems to be hampered by the extensive use of speaking in Norwegian language.

How do the VTS operators cope with complexity? The VTS operators are the most important 'system component' in the VTS, and as such significant to maintaining a stable output of safe performance in the MTS. The paper '*How vessel traffic service operators cope with complexity – only human performance absorbs human performance'* (Relling et al. 2019) explores both how the operators cope, and consequently render possible the requisite variety for the VTS as a system. How the operators cope is presented under the topics: operator experience, teamwork, organisational knowledge, and communication.

As the paper's title appeals to Ashby's statement that only variety absorbs variety, it is the VTS operator performance that absorbs the variety in the crew's performance. Further, the paper considers the unnecessary variety caused by variations between the VTS operators. In this term, the title could be understood in the opposite direction, as crew performance absorbs the variety in the VTS operator's performance.

6.3 A socio-technical system approach to the future VTS

The previous chapters have discussed what autonomy is, the human role in a future of autonomy and the Vessel Traffic Services' role in the Maritime Traffic System. The next two chapters will explore how to take a systems perspective and look to a future where the VTS contributes to safe coexistence between conventional and autonomous vessels.

Identifying potential solutions is a convergent design step for both systems engineering and human-centred design. While systems engineering mainly focuses on improving concepts, human-centred design aims at finding solutions that improves user-experience. This chapter explores an approach for designing a future VTS that succeeds in contributing to safe coexistence by considering both the role of the VTS in the MTS as a control system and at the same time appreciates the importance of facilitating for human performance in the system.

6.3.1 How can a socio-technical systems approach focusing on a democratic process, and systemic evaluation of internal and external consequences, be used in the early design phase of the future VTS?

Even if we take the most optimistic foresight of maritime autonomy, the share of autonomous vessels relative to conventional vessels will be small for many years. Consequently, the autonomous vessels and conventional vessels will coexist, meaning that they will operate within the same geographical areas and that they must relate to each other.

For the VTS, one can follow one out of two beliefs of how autonomy will change the role of the VTS. One belief is a development where the autonomous vessel has the same capabilities as conventional vessels. Conveniently for the VTS, the responsibility of solving the challenge of designing technical solutions that performs as human navigators is put on the ship designers, and this situation does not require any change by the VTS. The other belief is that the VTS will need to take ownership of the overall objectives of the MTS to be as safe and efficient as possible. For the VTS, this is an extensive approach that jointly considers the MTS and the VTS in designing future solutions. Such a joint consideration requires a holistic approach and not focusing on the actors in the system in isolation.

In the study, I have pursued the second belief of how the VTS can change to facilitate for safe coexistence. To be holistic, or taking a systems perspective, the study considers both a socio-technical systems approach and system-of-systems approach. The following sections are an extract of the discussion of designing the future VTS, a detailed description can be found in the paper *'A socio-technical perspective on the future Vessel Traffic Services'* (Relling, Praetorius, and Hareide 2019).

The development of socio-technical systems thinking. The joint optimisation between social and technical factors describes the perspective of socio-technical systems theory (Mumford 2006; Walker et al. 2008). The origin of the theory was seen in the 1950s when a group from the Tavistock Institute research program claimed that a separate social or technical approaches to systems was insufficient, and they presented the new socio-technical approach (Trist 1981). Even though the joint optimisation between social and technical factors have been a constant overarching focus, the area of interest and design principles of socio-technical systems have changed over the last 70 years and affected how the democratic focus on the workforce have shifted. Up to the late 1970s the objective was to increase quality in work life by humanisation of the work situation and involving employees (Mumford 2006). In the 1980s, automation and complexity opened up for a new interest in understanding cognitive activities in man-machine systems (Hollnagel and Woods 1983). From the mid-1980s, the organisational emphasis led to thinking in organisational levels and to understand human performance in light of latent conditions (Reason 1997). In the new millennium, interdependencies, user-involvement in systems accident models and resilience have opened for involving users to design systems being able to self-modification and to consider involvement on all levels of decision-making (Mumford 2006; Clegg 2000).

The relationship between systems and system-of-systems. Systems science has an orderliness that says that components that work together toward a common purpose are part of a system. If we zoom in on the components, these could again be a system with their own components. How we zoom in and zoom out, and where we put our focus, frames our system of interest. However, not all systems of interest have the same properties. Ackoff (1971) differentiates organisations from organisms by stating that organisms do not have purposeful elements and that organisms cannot display will. As such, he draws an important line and saying that we cannot zoom in to any level and expect the same properties to be present.

Maier (1998) draws a similar line of zooming out to large scale systems, and he expresses a difference between systems and system-of-systems, and explains this by *operational* and *managerial* independence. Operational independence is explained as if the system-of-systems is disassembled, the component systems *can* operate independently to fulfil their own purposes. Managerial independence considers that component systems to some degree *do* operate interdependently.

Maier suggests a set of design criteria underlining the independency in system-of-systems being different than systems design. He states that designers of system-of-systems need to consider the following four architectural principles. *Policy triage* points to despite having common goals, the independency between systems makes it impossible to control everything and one need to carefully consider what is possible to control in the system. *Leverage at the interface* between the component systems is important since the component systems to a large degree are independent, the interface is one of the few areas that is possible to design. *Stable intermediate form* is the ability to perform a stable output in the period until the system-of-systems is established. *Ensuring cooperation* is to design for incentives for cooperation since the independency makes it impossible to force cooperation.

In 2019, ISO issued a guideline for application of systems engineering in the context for system-of-systems, was issued (ISO 2019). This guideline complements the ISO 15288:2015 standard and provides a more comprehensive description of system-of-systems engineering. The ISO-guideline follows Maier and differs between systems and system-of-systems by operational and managerial independence. In general, the guideline offers more details on the processes listed in ISO 15288:2015. However, since the guideline is a generic description relevant to different system-of-systems, the focus is *what* to be covered in system-of-systems design rather than *how* to design. In the remaining part of the chapter, the focus is on how to design the future VTS.

Identifying the future role of the VTS is a democratic process. The development of socio-technical systems thinking points to various aspects that have been, and still are, important. An interesting point in this development is a change from a democratic process that has mainly considered *understanding* humans to later emphasising the importance of *involving* users in the entire design process. To allow for such involvement of users when designing the future VTS, the study suggests two steps; involve the organisation and nominate users.

Involving the organisation is important in order to anchor the need for change. This could be done by discussing why a change to the future VTS is important for the existence and relevance of the VTS itself. This could be done by a broad approach in the VTS organisation to openly discuss the challenges and benefits of changes to the VTS.

Nominating which users that will follow the design process is the second step. The multidisciplinary focus in both systems engineering and human centred design underlines that both technical and social expert knowledge are needed. Additionally, different competencies such as people responsible for managing, using, and supporting the future VTS should be involved. As discussed in 6.2.2, operators from the same organisational affiliation, such as VTS operators, might have different areas of interest. Consequently, a screening of these interests could be useful to select personnel with the wanted variety. In sum, the diversity of selected users is suggested to provide the necessary variety of knowledge necessary for designing the future VTS and also responds the one of the future challenges for systems engineering defined by Hossain et al. (2020) to include a wide array of interdisciplinary resources in systems development.

The internal effects for the VTS. A continuation of the democratic process to the future role of the VTS, is to identify the internal effects for the entire VTS-organisation. Rasmussen developed a levelled model of socio-technical systems that incorporate both the focus on organisational causes and the multiple interdependencies between the operator and organisations seen in systems models. For the VTS this can be used to ensure that all levels are represented in the design process, and a suggested visualisation of the various levels in the organisation is presented in Figure 15.

The visualisation must not be misunderstood as being focused only at the different levels, it is important to emphasise that the interactions between the levels and the focus on the overall objective, is the important element of the mindset of levelled thinking.

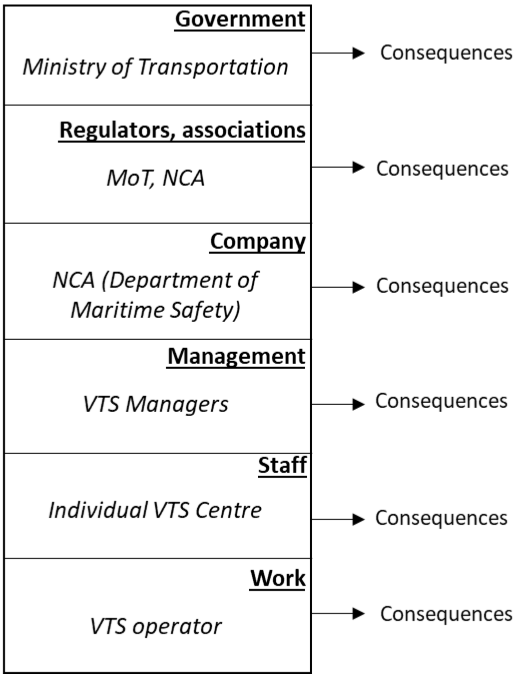


Figure 15: The Norwegian VTS organisation visualised in Rasmussen's levelled socio-technical model

A change in the future VTS will lead to different consequences on the various socio-technical systems levels. Applying the levelled socio-technical thinking has the benefit of not relying on a highly detail level. In an early design phase, the granularity is low, and the discussion is on an overall level. However, with a low detail level it is possible to identify obstacles that require attention. As an example, an isolated focus on the VTS operator can fail to see future solutions that are currently impossible due to regulations. Using the levelled method, this challenge is lifted to upper organisational level and processes that take longer to change can be initiated.

The external effects for the VTS, an interplay between the MTS and the VTS. In chapter 6.2.1, the MTS is presented as an abstract system that is context-dependent. The MTS discussed in the study is the collaboration of systems to achieve a safe and efficient traffic flow which is integrated through rules, regulations, and communications. As such, the component systems in the MTS have, at least partly, common objectives. Further, the MTS consists of independent managerial systems, such as shipping companies; and these companies are also capable of operating independently from each other. As such, following Maier's taxonomy, the MTS is a system-of-systems and his design principles for system-of-systems can be applied.

This perspective is essential for the study and outlines the rationale for why the VTS should take a central position in facilitating for the coexistence between autonomous and conventional vessels. The MTS is an abstracted system and cannot be linked to one specific organisation. However, by accepting that the component systems of the MTS share the objective of safe and efficient traffic, opens for discussing the responsibility for these objectives. On the one hand, it is possible to state that such a responsibility is distributed between the vessels being in the area at a given time. On the other hand, international obligations such as UNCLOS, described in 2.2.1, show that safety is also a governmental responsibility. In Norway, this responsibility remains on the Ministry of Transportation, and the use of VTS is one important measure to increase safety. The consequence is that the MTS is a system-of-systems that has safety as an objective, but the central measure for this safety is the VTS. As such, when designing the future VTS, it is necessary to explore how the VTS can fulfil the architectural system-of-systems design principles for the MTS.

The design principle of *policy triage* shows the difference between designing system-of-systems and systems. Opposed to systems design, it is not possible for the MTS as a system-of-systems, or for the VTS, to fully control the configuration (e.g. traffic flow) or the evolution (e.g. vessel design). To find a balance between what to control and what not to control is one of the challenging tasks in the design phase. *Leverage at the interfaces* considers the interface between systems. Since most of communication is currently done with voice, a future interface in a MTS with autonomous vessels might need different solutions for good interface, such as good communication, between all collaborating systems. To allow for *stable intermediate form*, testing and evaluation can be relevant, and the VTS needs to enable for this. Incentives are important to *ensure cooperation* in the MTS. Such incentives can be to balance formalised rules and control of the system with providing sufficient flexibility to users.

A socio-technical perspective on the future VTS. The socio-technical systems approach to the future VTS is considered as a proactive approach, where the VTS takes responsibility to facilitate for safe coexistence between autonomous and conventional vessels. The qualities of socio-technical systems being democratic points to the importance of both understanding and involving people from the entire organisation in a change process. Further, the levelled socio-technical systems thinking is a continuation of the democratic process, which ensures that consequences at different organisational levels and between organisational levels will be considered. Finally, designing the future VTS is congruent to designing a MTS. As the MTS is a system-of-systems, the VTS needs to encounter for how to implement the architectural system-of-systems principles when designing the future VTS.

6.4 The Vessel Traffic Services facilitating for safe coexistence in the future maritime system

The following chapter presents the final research area in the thesis, which is exploring if the VTS can facilitate for safe coexistence in a future maritime traffic system. The purpose is using a systems perspective to a future maritime traffic system and to suggest solutions that can move maritime autonomy to the next phase in the hype cycle.

The properties of the maritime traffic system and the context for the VTS is extracted from the results in the first three research areas: From the first research area, the understanding of what autonomy is will be used to describe the new concept in the traffic system where technology causes a significant change. Further, the role of the humans is emphasised by how the humans strengthen the system by being kept in the loop and being responsible. From the second research area, the thesis builds on the VTS being a control system and the importance of VTS operators for a safe coexistence in the MTS. The third research area outlines how to design a future VTS and emphasises the interplay between the VTS and the MTS and how the VTS must consider the architectural principles of a system-of-systems. Finally, the democratic process of involving personnel from various competence areas and levels of the socio-technical system is included.

6.4.1 Can the future VTS apply traffic organisation and traffic regulation measures to facilitate for safe coexistence between conventional and autonomous vessels?

The following sections are an extract of a study of exploring if the VTS can contribute to safe coexistence in a future maritime traffic system. The details from the study are presented in the paper 'It is not difficult, we could do it tomorrow: *The Vessel Traffic Services contribution to safe coexistence between automated and conventional vessels'* (in review).

The study follows the socio-technical systems approach as presented in 6.3. The democratic process is considered by a cooperation with NCA of assigning participants from different organisational affiliations and competence areas within NCA, and the experience level of the operators provides a broad operational and technical competence. The interplay between MTS and VTS mainly focuses on the system-of-system architectural design principle of policy triage. The internal effects for the VTS is to a lesser degree covered in this study but would be a natural next step when taking the results forward.

Data were collected in four workshops. The first two to define a maritime traffic system where an automated vessel can operate, and the last two to define how such a maritime traffic system can be regulated and organised.

- Workshop 1: Scoping a future maritime traffic system
- Workshop 2: Validating the maritime traffic system
- Workshop 3: Identifying challenges for today's VTS in a future MTS and how traffic regulation and organisation measures can be used in the defined traffic scenario
- Workshop 4: Validating results from workshop 3 by presenting a prototype of a MTS based on input from the third workshop and discussing if the prototype reflected the statements of the participants.

To outline the future maritime traffic system, a set of premises for autonomy in the MTS, are defined. The MTS is a 2025-scenario in Norwegian territorial waters in Storfjorden, one of the test areas for maritime autonomy. The autonomous concept is a highly-automated container vessel capable of following pre-programmed routes with only a minimum ability to perform additional actions. There are no humans on-board, and the vessel is supported by a shore centre. However, the planning of this shore centre needs to consider known human limitations, and thus it should not be designed for constant monitoring of the vessel. The VTS is still an important maritime safety measure in the 2025-scenario and needs to consider the system-of-systems design principle. Limitations such as manning or funding issues are not considered here. The VTS function is limited to policy triage, and the main challenge is to find the right level of control to avoid under- or over-control.

The results from the study are two-fold, one is a presentation of relevant safety measures for safe coexistence. The other is a prototype of the future MTS with the automated vessel, including the relevant safety measures.

Safety measures for safe coexistence. The safety measures identified in the study are presented under the topics of traffic regulation, traffic organisation, automated vessel and shore centre, and conventional vessel systems. These measures are summarised in Table 4.

Table 4: The identified safety measures to facilitate for safe coexistence in a future MTS

Topic	Safety measure	Description
Traffic regulation	*Extensive use of standard routes for conventional vessels*	More standardisation to reduce the variation of conventional traffic is considered as a prerequisite for coexistence with autonomy. The use of standard routes and TSS, in particular combined with VTS, provides more predictability in the MTS.
	Extensive use of Traffic Separation Schemes (TSS) for conventional vessels	
	Move pilot boarding areas away from 'hot-spot' areas where routes cross and/or traffic congestion is high	Moving pilot boarding areas away from hot spots is considered to reduce complexity in the MTS.
	Establish autonomous routes (AR) for exclusive use of autonomous vessels	Autonomous Routes (AR) will increase predictability and reduce misunderstandings, if they are well known to all navigators and labelled with a unique identity. The AR should be placed in the centre of the fairway and when used together with TSS, in the separation zone of the TSS.
	Pre-approval for autonomous concepts	Autonomous concepts are limited to operate on some, specific routes, and need pre-approval for the concept. Autonomous concepts should only operate within a VTS area.
General comments for traffic regulation: Traffic regulation in narrow waters is challenging since there may not be enough space to establish different routing measures. Additionally, formalising new types of regulations internationally is considered to be a protracted process.		
Traffic organisation	*VTS changing role from ad-hoc response to taking tactical responsibility*	The VTS needs to resolve situations at an earlier stage than today and consequently move towards a tactical control mode.
	Use of time slots	In addition to increased predictability in the MTS, the use of time slots is assumed to give added value in coordinating other services such as pilots, tugs, and port services.
	Clearances for departure	This is already in use to some extent, but the compliance to the clearances are not sufficient and needs to be improved to be an effective measure
	Condition-based clearances	This concerns clearances to proceed on the route if one or more conditions are fulfilled. In some situations, these clearances could include a deconfliction that is not in accordance to COLREG.

		However, if these clearances are provided early and communicated to the actors in the immediate vicinity, it is not considered a problem.
	Clearance for routing	Clearances for standard routes or TSS are expected to provide adequate predictability for separation. Additionally, the autonomous vessel needs to be cleared for the assigned route.
	Automated traffic organisation solutions	For traffic frequently trafficking an area, an automated traffic organisation, or resolution, can be developed and allow for the vessel to self-deconflict
General comments for traffic regulation: To effectively organise traffic, the operator needs to be supported by sufficient radar- and radio coverage.		
The automated vessel and shore centre	*Can follow a specified route and speed*	The automated vessel must be capable of accurately following a route and speed
	Have redundant safety critical equipment	The automated vessel must increase its reliability through redundancy
	Assess if an autonomous vessel needs to be categorised as having 'limited ability to manoeuvre'	The categorisation of 'limited ability to manoeuvre' refers to a vessel which by the nature of her work is not able to follow the COLREG. Using this category has both benefits and challenges. A benefit is that such a categorisation is relatively normal around the world and would clearly indicate the vessels capability. A challenge is that such a categorisation gives the autonomous vessel a priority over other vessels, since it does not need to give-way to other vessels in any situation.
	Can be stopped from the shore centre and consequently needs a station keeping ability	If a problem occurs, the vessel needs to be able to stop and keep its position until the situation is over.
	Marked with a distinct AIS-tag	To distinguish the automated vessel from other vessels, AIS-tag is useful.
	Conspicuous hull colour	To make it easier to spot, a conspicuous hull colour could be used.
Conventional vessels	*Stricter traffic regulation*	Stricter traffic regulation, through routing is a prerequisite for safe coexistence
	Displaying Autonomous Routes on the ECDIS and setting up alarms if entering an AR	The Autonomous Routes must be easy to see on the ECDIS, and alarms can be used to warn conventional vessels if they approach such routes.

A prototype of a future Maritime Traffic System. The first two workshops described a 2025-scenario in the test area of Storfjorden. In this system, several conflict situations were described. The identified conflict situations were linked to the safety measures identified in the third workshop and validated in the fourth and last workshop. In the following section, the prototype of the MTS with an automated vessel sailing from Aalesund to Sykkylven is presented.

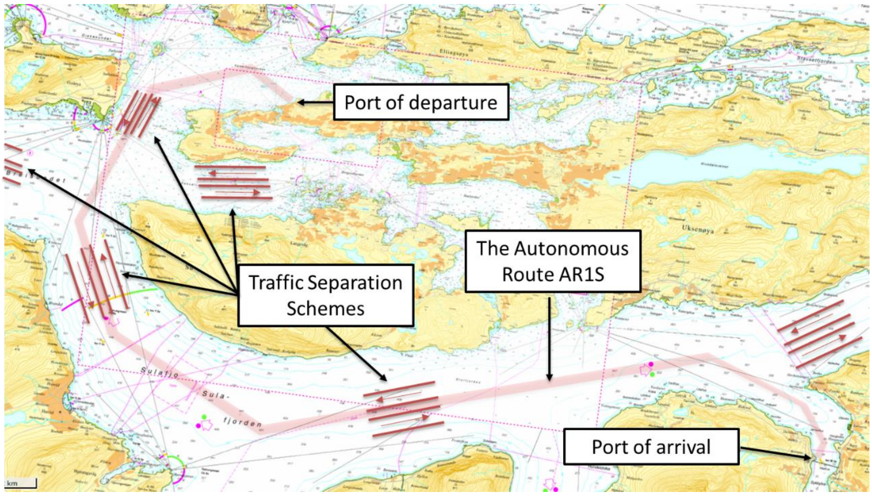


Figure 16: The prototype of the MTS with an automated operation in the autonomous route AR1S and Traffic Separation Schemes

Table 5: The prototype of a future MTS where an automated vessel sails from Aalesund to Sykkylven

Time	Situation	Reasoning
09:00	The container terminal notifies the shore centre (SC) that the containers will be loaded on-board at 11.00.	The SC is responsible for planning and coordination the operation in accordance with the operational criteria. SC will request route and departure time via SafeSeaNet. Some communication between VTS and SC could be electronically.
09:10	SC checks weather forecast and loading conditions, and contacts port of arrival to ask when they are ready to receive the containers. Due to the quay being occupied, the arrival port request arrival of the vessel to be at 15.00.	
09.15	SC programs departure from NO AES at 11.00 and arrival at NO SYK at 15.00 and choose route 'Autonomous Route 1 South' (AR1S) for the voyage. Based on weather and current the SC calculates a transit speed of 6 knots.	
09.20	SC transfers the requested route, speed, and departure via SafeSeaNet (SSN).	
09.20	VTS receives "request for departure" from SC. The request is routed from SSN directly into the VTS Operator Support Station (OSS) The OSS informs that the departure conflicts with another departure and presents the first available time slot to be 11.20.	VTS should be responsible for time slots. VTS approves routing, speed, and departure.

	The VTS operator assigns the 11.20-time slot to the automated vessel and this triggers a “preliminary schedule for departure” to SC.	VTS should be supported by technical solutions.
09.25	SC receives “preliminary schedule” and speed is automatically updated to 7 knots to meet requested arrival time at 15.00.	

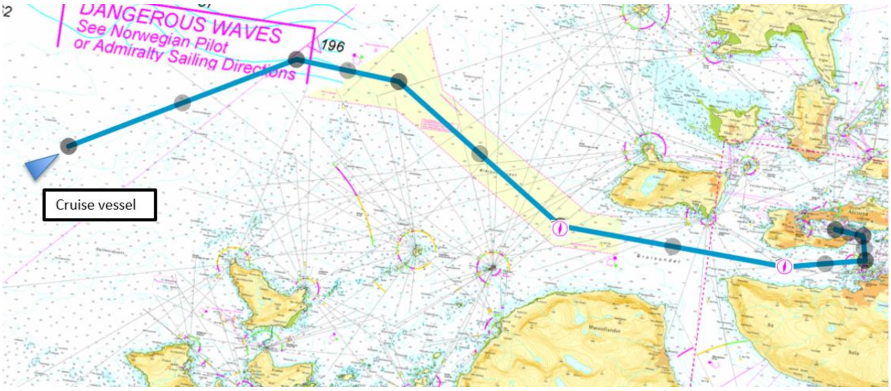


Figure 17: A cruise vessel reports to enter the area, and receives a condition-based clearance from the VTS

Time	Situation	Reasoning
10.30	A cruise vessel checks in on the VTS frequency and report 30 minutes until entering VTS area and requests clearance for entry in accordance planned route AES E1 at time 11.00 VTS checks the OSS and confirms that the cruise vessel is on schedule for the assigned time slot for entry. The OSS warns that with current speed at 15 knots, the cruise vessel will conflict with the automated vessel. VTS gives the cruise vessel clearance to entry AES E1 at maximum speed 13 knots and informs about traffic is automated vessel at AR1S. Cruise vessel is cleared to proceed and cross aft of the automated vessel. The VTS enters speed 13 knots and checks that time for pilot boarding is changed by 12 minutes. The SSN automatically informs the pilot distribution centre. The cruise vessel reads back entry clearance.	Standard routes should be used by conventional vessels. Pilot boarding should be moved away from hot spot areas. VTS will organise traffic by condition-based clearances. The VTS should take a role of organising the traffic by planning. If done in proper time COLREG situations will not occur. OSS and SSN should support the VTS operator.

11.00	VTS receives a phone call from the local sail club who informs about a planned training in the area. The VTS informs about AR1S is active, and this implies that if the sail boats cross the route, they are give-way vessels.	Automated traffic regulation will affect and potentially could reduce flexibility for other traffic.
11.10	SC notifies the container terminal that departure is scheduled in 10 minutes. SC scans the area with their sensors.	The automated vessels will have sensors to monitor the situation around the vessel. SC is responsible for initiating departure.
11.10	VTS OSS informs VTS operator of 10 minutes for departure of automated vessel and the VTS operator scans the AR1S for traffic.	VTS needs sufficient radar coverage for the entire area.
11.20	VTS activate AR1S and transmits the clearance for departure on AR1S speed 7 knots on the radio frequency.	VTS is responsible for clearances.
11.20	SC initiate departure procedure and confirms with camera that all navigation lights works, and checks AIS-signal is on.	The automated vessel must be easy to recognise.

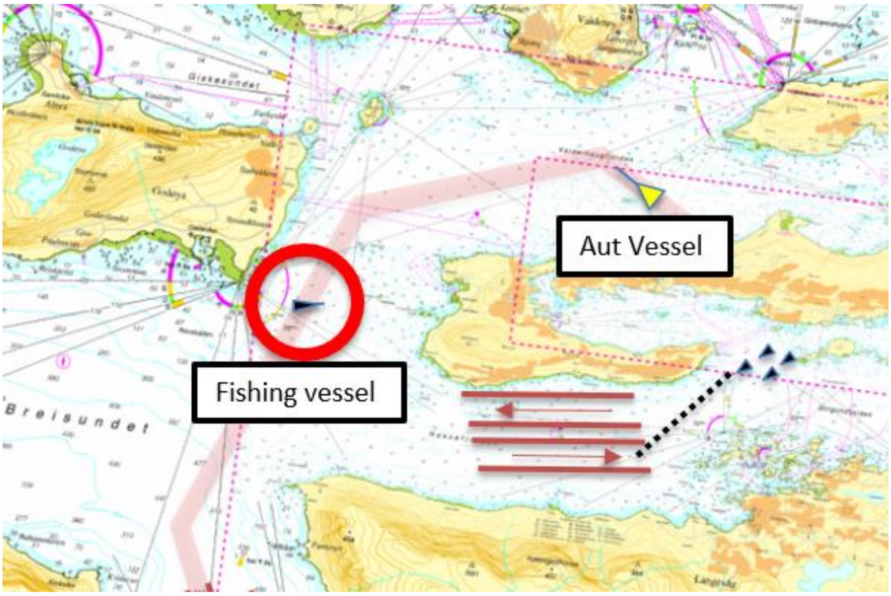


Figure 18: A fishing vessel starts fishing in the AR1S. The VTS is warned by an alarm.

Time	Situation	Reasoning
11.30	An alarm is triggered at the VTS. The radar has detected a track inside AR1S. The VTS operator sees that the track has no AIS signal and no one is responding on the VTS work channel on radio. The VTS operator calls the vessel on the distress channel (channel 16). A fishing vessel responds and acknowledge the VTS instructions of setting course east immediately.	VTS needs sufficient radar and radio coverage for the entire area. Standardised routes allow for precise alarm criteria
11.40	The cruise vessel confirms AIS contact with the automated vessel.	The automated vessel should be easily recognised by a special AIS-designator.

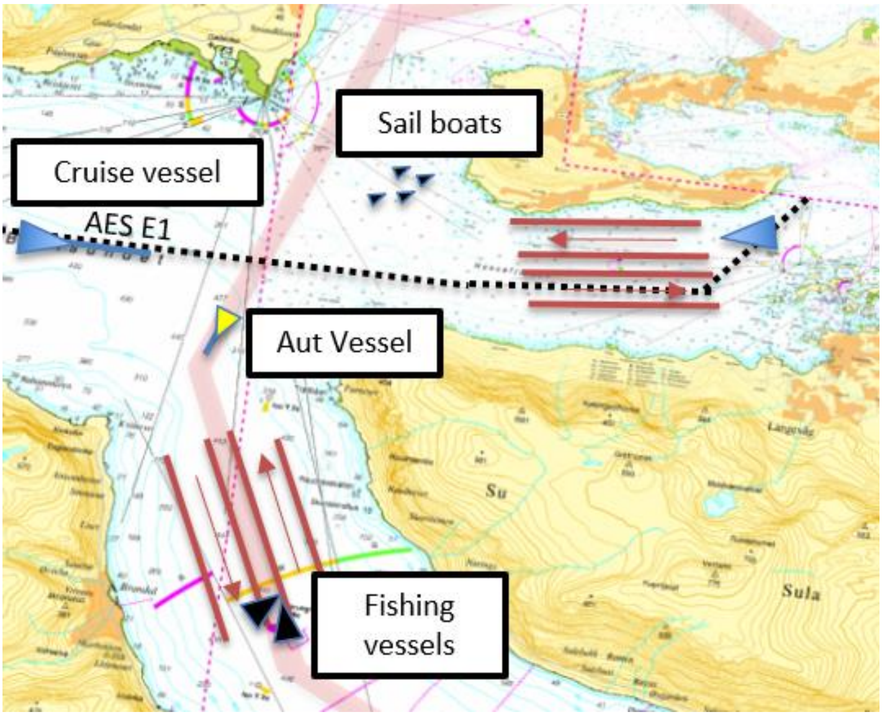


Figure 19: If a situation occurs in the autonomous route, the automated will reduce speed and never leave the autonomous route

Time	Situation	Reasoning
12:10	A fishing vessel with engine failure gets an alarm on the ECDIS of drifting inside an active autonomous route An alarm is triggered at the VTS. The radar has detected a track inside AR1S.	Conventional vessels could be warned if they are inside an active autonomous route.

	VTS receives a radio call from the fishing vessel saying they have assistance from another fishing vessel that will start towing as soon as the towing line is secured. The fishing vessel asks if the automated vessel could pass west of them. VTS responds that course deviation outside AR1S is not possible, but the automated vessel will reduce speed or stop. VTS calls SC and instructs the automated vessel to reduce speed to 5 knots. The SC executes the speed reduction The fishing vessel reports that towing is initiated and that they are clear of AR1S VTS calls SC and informs that the automated vessel could proceed as planned. SC increases speed of the automated vessel.	The automated vessel is capable of adjusting speed but will not leave the autonomous route. The SC is responsible to execute instructions from the VTS.

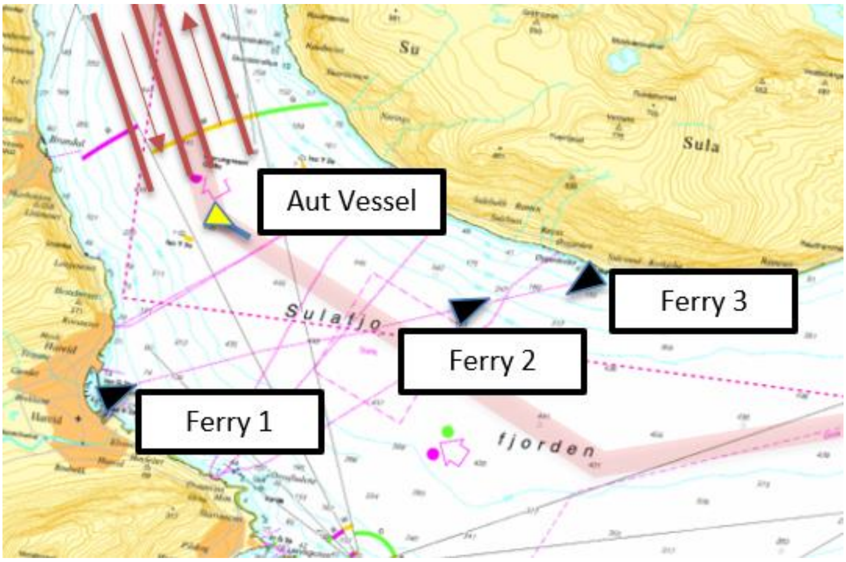


Figure 20: An automated solution to resolve situations between the automated vessel and vessels that frequently trafficking the area is suggested

Time	Situation	Reasoning
12:50	The automated vessel approaches a busy ferry crossing area. The automated traffic organisation system has suggested that Ferry 1 deviates 10 degrees port and Ferry 3 increases speed by 2	An automated technical solution to resolve situations between the automated vessel and vessels that

	knots and crosses in front of the automated vessel. When the navigators of Ferry 1 and 3 have accepted the VTS is informed by a green signal on their work station. The extra fuel consumption is logged by the ferries and reported to their shipping company.	frequently trafficking the area is suggested.

Figure 21: The automated vessel might experience conflict situation with vessels under VTS control and vessels not controlled by the VTS

Time	Situation	Reasoning
13:15	A passenger vessel is outbound and is notified by the VTS about the automated vessel. The passenger vessel reports AIS and radar contact and they will cross AR1S and enter TSS westbound and confirms they will maintain separation from the automated vessel.	VTS needs sufficient radar and radio coverage for the entire area. The automated vessel should be easily recognised by a special AIS-designator.
13:20	The VTS and SC are warned about a small high-speed leisure boat which is on a collision course with the automated vessel. The automated vessel is categorised as 'limited ability to manoeuvre' and even though the leisure boat approaches on the starboard side, the autonomous vessel is the stand-on vessel and maintains speed and course. After an unsuccessful call on all radio channels, the VTS calls the SC. SC informs that the automated vessel has automatically initiated sound and light warning. The VTS observes that the small leisure boat crosses in front of the automated vessel, but inside the published safety zone for the automated vessel. SC downloads video recording from the automated vessel and confirms that they will create a non-conformance report.	VTS needs sufficient radar and radio coverage for the entire area The automated vessel could be categorised as limited ability to manoeuvre. The automated vessel should have some pre-programmed solutions for difficult situations. Alarm criteria could be well defined based on predefined routes.

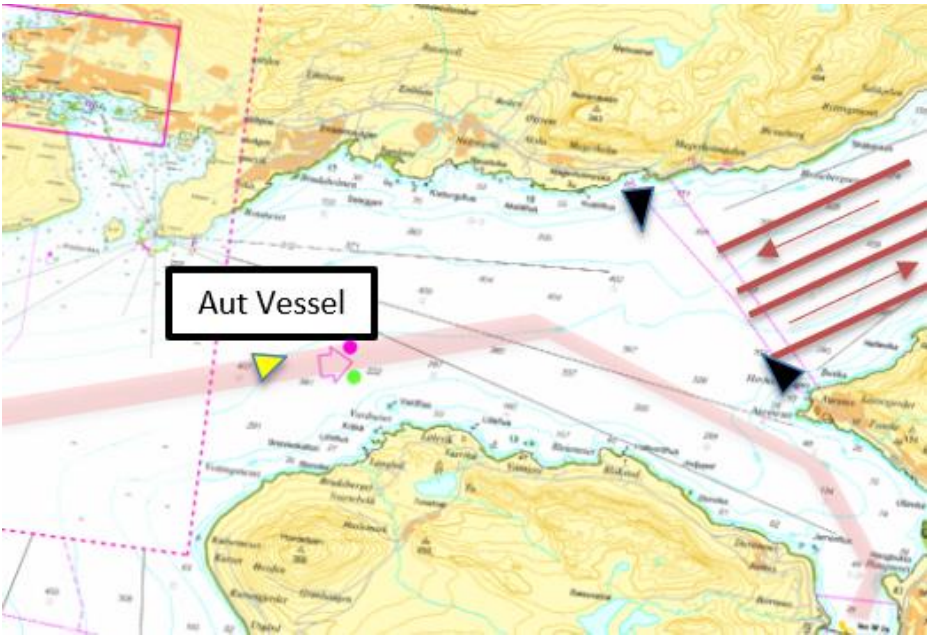


Figure 22: In case of a black-out, the automated vessel should have a back-up solution that keeps the vessel inside the autonomous route

Time	Situation	Reasoning
14:30	The automated vessel has a black-out. The SC is warned immediately, and the VTS is warned 2 minutes later. The automated vessel uses emergency power to stop the vessel and use a back-up dynamic positioning system to remain inside the AR1S. VTS scans the area and informs the ferries east of the automated vessel. The ferries could confirm the VTS' radar picture; the automated vessels lay still in the middle of the AR1S. SC initiates procedure for black-out and orders tug	VTS needs sufficient radar and radio coverage for the entire area The automated vessel should have some pre-programmed solutions for difficult situations The SC is responsible for the operation of the automated vessel
15:00	SC manages to restore contact with the automated vessel. SC sends a request to recommit voyage to the VTS The VTS issue clearance to continue voyage. SC sends order to continue of voyage to the automated vessel. Speed is increased to 11 knots due to delay.	SC will coordinate and plan the voyage SC will request route and departure time via SafeSeaNet Some communication between VTS and SC could be electronically.
15:20	The automated vessel arrives port.	

Safe coexistence in a future Maritime Traffic System. The study identified a wide range of measures to allow for safe coexistence in a future MTS between an automated vessel and conventional vessels. The fundamental measure for such coexistence is standardisation of traffic. Conventional vessels can be regulated through standard routes and TSS, while automated vessels follow separate Autonomous Routes. The standardisation increases predictability in the MTS, and consequently reduces complexity. However, standardisation comes with a price, it reduces the flexibility for the vessels in the MTS. The trade-off between standardisation and flexibility reflects the system-of-systems architectural design principles policy triage and ensuring cooperation. Avoiding over- and under control is an objective for policy triage. The study indicates that the complementary systems and design thinking process can contribute to finding the balance. The systems design process will underline the importance of structure, while the design thinking includes users to protect the necessary flexibility in the system.

For traffic organisation, the most prominent result is the statement that the VTS needs to take a new and different role and go from solving situations ad-hoc to taking a tactical responsibility in planning and resolving conflict situations. This change is driven by digitalisation, but not only through autonomy. Regardless of autonomy, digitalisation allows for sharing of more information between vessels and between shore and vessels and could make the VTS as we know it today, obsolete. Consequently, the VTS can be forced to take new roles to uphold its position as a major contributor to maritime safety. Several measures for traffic organisation have been identified, and time slots, clearance for departure, clearance for routing and condition-based clearances reduces the variety in the MTS and allows the VTS operators to cope with the remaining complexity. Additionally, the use of technology in combination with standardisation can augment the VTS operators. Standardised traffic increases the possibility of defining and using alarm settings to warn operators of abnormalities, to make better use of calculation of meeting points, and to provide better traffic resolution advice.

The prototype of a future MTS where the automated vessel has a problematic voyage where several conflict situations, shows that the challenges can be matched with solutions. The weakness of such matching is that both challenges and solutions were suggested by the same groups of participants. To strengthen the study, the prototype should undergo additional interactions with other users to find more conflict situations, and potentially more and better solutions.

The results indicate that autonomous and conventional vessels cannot be regulated equally. A consequence of implementing the measures from the prototype of the future MTS, is a different distribution of the responsibility for separation between vessels than in the present MTS. The conventional vessels and the VTS are given additional responsibility compared to today, while the shore centre is given little responsibility in this future MTS. In many discussions of autonomy, the shore centre operator is given the same role and responsibility as a navigator. In such discussions, the shore control centre operator seems to be exposed to the challenges of ironies of automation; of being out of the loop until something goes wrong, and then instantly being responsible to take over a difficult situation. In the abovementioned prototype, the shore centre is only responsible for requesting clearances and starting and stopping the vessel’s voyage. Obviously, this is a major change for the maritime industry and such a change can easily be stopped by saying that the rules do not allow for this. The identified effects of this increased responsibility for the conventional vessels is not further explored. However, the largest change is to the VTS, and the prototype shows that the VTS can be a major contributor to a safe coexistence. To allow for this contribution, the VTS must take a new role and implement a set of new measures. To take such role and to implement new measures is considered feasible and supported by a statement showing this is not perceived as neither futuristic nor unrealistic: “this is not difficult, we could do it tomorrow”.

7 Contribution

The initial optimism of maritime autonomy has faded, indicating that the development can be in the hype cycle's trough of disillusionment. The focus on maritime autonomy is currently mainly on the vessel, even though we know that engineering socio-technical systems should include the knowledge of human performance and human contribution. This study aims to close the research gap between the existing technology focus on maritime autonomy and how a systems perspective could enable for autonomy in the maritime industry. The systems perspective, considering both human and system performance, has shown to advance the development towards the next phase of the hype cycle. The study has the following contributions:

Scientific contribution. The study has unpacked resilient performance as an overlapping topic between systems theory and human factors theory and used this in systems design. Resilient system performance and maintaining a stable output is essential for safety, and control systems contribute to such stable output. The study contributes to the design of a control system by discussing how human performance and system performance is relevant to achieve stable output.

The human's performance variability is a known prerequisite for functioning systems, however, the study contributes to underline the relevance of human performance in future systems. By emphasising that the humans will strengthen the future maritime system, claiming that the humans should be in the decision loops and that humans will be overall responsible, the thesis contributes to balance the apparent one-sided focus on technology. In short, the study contributes to prevent autonomy to try making humans as being as machines, and machines as being as humans. To support this balance, a control and responsibility model to remain the humans in the loop is presented.

To understand the systems performance of a control system, the study has emphasised the different roles of a control system in a system versus a system-of-systems. In both cases, control systems contribute to stable output, but the study shows that the independency in system-of-systems limits the influence the control system has on the systems. Due to the independency in system-of-systems, the study proposes considering the architectural design principles for the system-of-systems when designing the control system.

Methodological contribution. The study has combined a Design Research Methodology (DRM) with a complementary mindset of systems thinking and design thinking. By combining the three, the study contributes to connect the approaches and providing a more detailed description of potential activities to be carried out in the different design stages.

The study has suggested to further develop the complementary mindset to a system-of-systems by suggesting a socio-technical approach. This approach supports design thinking by suggesting a democratic approach that assess the consequences for a change for all levels in the socio-technical system

As discussed in chapter 3, two future challenges for systems engineering are to better address complex systems and their problems, and to allow for wider interdisciplinarity in design and development of systems. The study has suggested that complex systems can be addressed by applying the dynamical systems theory and using a combined perspective of external and internal description of systems. Further, to allow for a wider interdisciplinarity, the democratic process in the levelled socio-technical systems approach is useful in an early design phase.

Industry contribution. The study has explored the present VTS role and discussed the future VTS role. In the study of the present VTS role, the study has explored how the VTS operator's performance variability is necessary for maintaining a stable performance of the MTS. Further, the study has contributed to highlight that all variability is not necessary.

The democratic process of gradually involving more VTS personnel in the development process follows the trends in systems safety models and resilience. This involvement contributes to an ownership of the process and the result.

For the future VTS role, the study shows that digitalisation is likely to cause significant changes for the VTS regardless of autonomy and a shift from being an ad-hoc problem solver to a tactical controller is a prerequisite for autonomy but can be necessary even if autonomy is not introduced. However, by designing a future MTS with an automated container vessel in territorial waters, several safety measures were identified to achieve a safe coexistence between an autonomous vessel and conventional vessels. As such, the study has contributed to show that the VTS can play an important role for the development of maritime autonomy, and taking this role is considered to be feasible.

8 Future work

The motivation for the research was to present a different approach to maritime autonomy than a one-sided technology focus. My research has used a dual perspective, systems and humans, to discuss how the VTS can facilitate for safe coexistence. I have combined a design research methodology with a complementary mindset of systems engineering and human-centred design, that all consider interaction and iteration. This has proved to be a valuable guidance for the research. However, a recommendation for future work is developing better recommendations for when to change perspective between system and humans. In my work, this has been subjective, and as discussed earlier, could be negative for the dependability of the study.

Future work could also use my stance of a different approach and continue to explore the VTS role. Such work could both be to look wider and deeper. A wider approach could take the results from the prototype and invite navigators and pilots to discuss identified and new problems and solutions. A more in-depth study can apply the remaining three architectural design principles, and further explore the effects on and between the socio-technical system levels.

Finally, a broader challenge is how to discuss maritime safety. In my thesis, I left my initial thoughts of finding epistemic objective claims to safe coexistence. Future maritime research could benefit from discussing if it is possible to find more convergence between objective and subjective claims. If so, interesting possibilities of triangulation of methods that could improve the validity of research can be explored.

9 Conclusions

In the Research Clarification stage, Research Question 1 concerns the human role in the future maritime system. This question was explored by two sub-research questions of what autonomy is, and how a systemic human-technology approach in maritime can be adopted.

The research has concluded that:

- The frequent use of the term autonomy with different interpretations, creates an ambiguity of what autonomy really is. To develop maritime autonomy, it is imperative to reduce the ambiguity of the term autonomy.
- Self-governance is not achievable nor desirable, and to design a system that is being autonomous in terms of total self-governance, should not be the objective.
- Autonomy can be considered as being the process of increasing system performance by utilising technology and optimising the human-technology interaction.
- Knowledge of how humans contribute to maintain a system stable in a shifting environment should be utilised in order to strengthen future systems.
- The overall responsibility for top-functions, such as navigation, will, at least for the near future, remain on the humans.
- Control is the link between responsibility and authority (executing agent). Control is how to allocate constraints and tasks to the executing agent, and to provide the right information of system status, rationale for decisions and decisions to the responsible person.

The first Descriptive Study (DS I), responds to the Research Question 2 of what the Vessel Traffic Services' role in the maritime system is. Two approaches were used to answer this question, one systems approach to learn how the VTS contributes to the MTS. The other, a human-centred perspective, by unpacking how the VTS operators use expert knowledge and strategies in the interaction with vessels.

The research conclusions of this stage are:

- Being a control system points to a responsibility for stable performance in the MTS, and one important aspect of stable performance is safety.
- The VTS needs the same or larger variety in its attributes as the variety in requirements in the environment, to contribute to stability, or a safe coexistence, in the maritime traffic system.
- The challenge to the stable performance is the complexity caused by both external and internal variations to the VTS. The external variations are the shifting demands of the environment, namely variations in the demands of the vessels in the area.
- The requisite variety for the VTS will be achieved by functional adequacy through performance that meets the demands in the environment. At present, the most important measure of requisite variety through functional adequacy, is human performance variety.
- The VTS operators are the most important 'system component' in the VTS, and as such significant to maintaining a stable output of safe performance in the MTS.
- The VTS operators cope with complexity based on operator experience, teamwork, organisational knowledge, and communication.
- The VTS operators have a performance variety that allows them to cope with the variety in situations.
- There are variations between VTS operators that are not necessarily due to external variations. These internal variations are considered as unnecessary variations in performance.

The Prescriptive Study concerns Research Question 3 of which approach can support design of the future VTS. The study suggests a socio-technical systems approach considering both the system and humans, and concluded that:

- A socio-technical approach to designing the future VTS includes a democratic process to assess the internal effects and the external effects for the VTS.
- Internal effects to the VTS can be identified in a levelled socio-technical system where effects are described at various levels and between levels from the operator level to a societal level.
- External effects to the VTS can be identified by assessing how the VTS can contribute to the system-of-system architectural design principles for the overarching system, the MTS.
- The independencies in a system-of-systems, make It is essential to differ between designing a control system in a system, and a control system in a system of systems.

The final stage, the Descriptive Study II, explores Research Question 4 of how the Vessel Traffic Services can facilitate for safe coexistence in a future maritime system by applying traffic organisation and traffic regulations measures. The conclusions were:

- The VTS must take a tactical responsibility for traffic organisation to facilitate for safe coexistence between autonomous and conventional vessels.
- The existing traffic organisation measures, such as departure clearances and condition-based clearances, must be used more and stricter to provide for safe coexistence.
- New traffic organisation measures, such as time slots and route clearances, must be considered.
- Regulating traffic, both conventional and autonomous, is a prerequisite for safe coexistence. This includes more use of standard routes for conventional and that autonomous vessels operate in designated autonomous routes.
- Conventional vessels must expect stricter traffic regulation in areas with autonomy.
- A consequence of implementing traffic regulation and traffic organisation for safe coexistence is a different distribution of the responsibility for separation between vessels than in the present MTS. A future MTS with these measures will give additional responsibility to the conventional vessels and the VTS, while the shore centre is given little responsibility.
- A prototype of a future MTS with an automated vessel, shows that the identified challenges can be matched with solutions that ensure safe coexistence.
- The prototype shows that the VTS can be a major contributor to a safe coexistence, and taking a new role is not perceived futuristic nor unrealistic.

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Appendix – Paper I to IV

Paper I

A Human Perspective on Maritime Autonomy

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Abstract. As for all of the transport segments, autonomy is gaining increasing interest by researchers and for development in the maritime industry, and introducing autonomy is expected to create new possibilities to increase efficiency and safety. Autonomy could lead to drastic changes in roles and responsibilities for involved agents (both technical systems and humans), and these changes will be an important driver for changing the rules which regulate the responsibilities of the involved actors in the maritime domain. This paper suggests a perspective of autonomy as a process of change as opposed to a defined state. The paper discusses three areas that warrant more attention in the development of autonomy in navigation in the maritime industry. Firstly; rather than the traditional reductionist safety models, it considers complexity in maritime systems with increased autonomy and explore systemic safety models to amplify positive human performance variability. Secondly; it argues that humans will be important also in systems with increased autonomy, and discusses the human involvement on *strategic, tactical* and *operational* levels. Thirdly; it discusses the importance of defining the concepts responsibility, authority and control from the perspective of *humans*, rather than that of the *vessel*.

Keywords: Human centred design · Maritime autonomy · Methods of control Responsibility · Authority · Remote operations

1 Introduction

There is a belief that the future of maritime industry will see an increased use of autonomous solutions. The International Maritime Organisation (IMO) decided to include the issue of marine autonomous surface ships on its agenda in their Maritime Safety Committee in June 2017 [1], which is a solid sign of the importance of the topic. The dissension grows when discussing what autonomy *is*, and *how* it will affect maritime industry.

In contrast to what seems to drive the development of maritime autonomy, autonomy as a concept has no direct link with technology. Autonomy has been used since the early 17th century and comes from the Greek *autonomia*; from *autos* “self” + *nomos* “law”. The Oxford Dictionaries explains autonomy as *the right or condition of self-government*, and further as the *freedom from external control or influence:*

D. D. Schmorrow and C. M. Fidopiastis (Eds.): AC 2018, LNAI 10916, pp. 350–362, 2018.
https://doi.org/10.1007/978-3-319-91467-1_27

independence [2]. In maritime history, we can easily find examples that fall under the definition of autonomy. The explorers who sailed into the unknown more than 700 years ago were self-governed from when they left the harbour, with no shipping company or authority to influence their choices. Another example would be fishermen sailing from Europe to the Antarctic 100 years ago, staying away for months, also with little or no influence from their owner in the home country. However, arguing that the maritime domain was more autonomous in the past than what we expect of the future might not be very helpful to reduce the dissension about what autonomy is, but it does show that we might interpret autonomy differently than the original meaning of the term. This paper discusses what autonomy is today, and further elaborates on the human role in the development of autonomy in maritime systems. A system is defined as "an assemblage or combination of functionally related elements or parts forming a unitary whole" [3]. The parts of the system could be technical or human agents, where an agent is defined as a "'thing' in an environment with capacities to sense states and effect aspects of the environment" [4].

2 What Is this Thing Called Autonomy?

Apparently, the term autonomy is used differently in colloquial language than in the technical definition. In addition it is interpreted in various ways both in the maritime industry and other industries. Automation and autonomy are often used interchangeably in the discussion of the technological development in the maritime industry. Parasuraman and Riley [5] define automation as "*the execution by a machine agent (usually a computer) of a function that was previously carried out by a human"*. Some attempts have been made to create a more distinct difference between automation and autonomy by transforming *Levels of Automation* (LOA) developed by Sheridan and Verplank in 1978 into various *Levels of Autonomy* [6]. The attempts have neither been able to create a common understanding of the distinction between automation and autonomy, nor reach consent on whether using *levels* is suitable for describing concepts. Endsley [7] states that using *levels* is beneficial to communicating design options to stakeholders in both automated and autonomous systems, and especially for explaining the continuum between fully manual and fully automated. However using levels to describe autonomy has been criticised for being unidimensional and not reflecting the real problems in developing systems, and for not allowing for dynamically changing functions in various contexts [8]. Parts of this criticism is rejected by Kaber [9] who claims that it confuses automation with autonomy, and he states that the *"research focused on one construct (i.e automation as a technology) yet made criticism from the perspective of another (i.e autonomy as a state of being)"*. To distinguish between automation and autonomy is difficult, and the Society of Automotive Engineers (SAE) has decided to put the term "autonomous" in their section of deprecated terms. They state that the term has become synonymous to automation since the use of it has broadened to not only encompass decision-making but include the entire system functionality [10]. Parasuraman [11] presented his version on the Levels of Automation, where the highest level of automation is defined as the computer deciding everything, acting autonomously, and ignoring humans. According to this definition, autonomy is gained at the highest level of automation, which could support the criticism of unidimensionality of the concept of autonomy.

There is no unified definition of what autonomy *is* in the context of developing systems. The challenge is apparently to define *a state of being* which includes all aspects of the benefits and complications within human and technology interaction in various contexts and changing scenarios. The reason for introducing autonomy in a system is to improve the performance of the system; hence, increased autonomy will not be a goal in itself. Relating autonomy to a change process based on system needs will give various answers of what autonomy is from system to system, and will vary over time. This paper suggests that autonomy, similar to Parasuraman and Riley's definition of automation, is a process rather than a defined state. Similar to automation, the use of technology is a main component in the change process, and autonomy especially implies the use of digitalization such as sensor fusion, control algorithms and communication and connectivity [12]. The other main component in the change process is the degree of involvement of humans in the operations, and the aim to reduce human presence in dangerous and hostile environments [13, 14].

The similarities between automation and autonomy are many, and several of the challenges Dekker and Woods [15] discuss about how humans and technology get along in highly automated systems, is the same challenges more recently discussed considering autonomous operations [16]. With an interchangeable use of the two terms, it is tempting to follow SAEs path by discarding autonomy as a term and stick to the use of automation. However, there is one solid argument for keeping autonomy as a term. While automation could span from a simple exchange of functions between humans and technology, to highly automated systems comparable with autonomy, autonomy implies a *significant* change to the system. This significant change also imply that understanding all effects of changes are more complex. Lee [17] describes autonomy from a network perspective, where automation and people are nodes in a network that produce emergent properties that are not predictable by looking at the nodes in isolation.

The main difference between autonomy and automation is therefore that autonomy implies a significant change to the system where emergent properties are expected to affect the performance of the system. This perspective takes into account that there is no single solution on what to change, nor is there a unified end-state of the change process. It opens for autonomy being different from system to system, varying over time and being affected by the context. This approach might seem complex and a rejection of the existing research on autonomy, but the purpose is the opposite. By agreeing on a significant level of the change, it is possible to discuss how complexity and emergent properties will affect performance of a system with increased autonomy. This will not limit autonomy to a few defined factors, but will be dynamic and adaptable based on context and the previous state/s of the system.

3 Humans and Autonomy in Maritime Systems

There are two main directions of development in the maritime domain that fall under the above-mentioned perspective of autonomy. One is the development of self-navigating vessels[1], and the other is remotely operated vessels. The similarity is the aim to reduce human presence on the bridge or even to reduce human presence on the entire vessel. Both directions could cause a *significant change* to maritime systems when humans are moved away from the bridge, to a position on shore (or elsewhere). The difference between remotely operated vessels and self-navigating vessels is *how* the humans are involved by remotely operating the vessel or taking a role of controlling the operations by monitoring or supervising from a distance. As discussed later in the paper, the two directions will create different challenges to overcome.

Increased autonomy is expected to provide benefits such as less environmental emission and increased efficiency and safety [18]. This paper is limited to discussing the challenges related to the effect on safety, and the navigation function, where the humans operate, monitor or supervise navigation from shore. The paper discusses the human involvement in three areas; a systemic approach which advocates for human as strengthening the system, the human role on strategic, tactical and operational levels and finally how humans will be responsible and remain in control in systems with increased autonomy.

3.1 Humans Will Strengthen the System

Increased safety is an expectation and a motivation for developing solutions with increased autonomy. It is claimed that increased safety will be achieved by reducing the likelihood of *human error* when introducing more autonomy [12, 19]. There is no reason to dispute the fact that reducing human error will increase safety, but it is necessary to be wary of the belief that introducing more technology is coherent to reduction of human error, and Bainbridge "Ironies of Automation" [20] is still as valid today as it was 35 years ago [21].

Since autonomy entails significant changes to systems, it could be compared to what Boy [22] defines as a typical twenty-first century problem, with *"global and non-linear"* problems where the number of components and interactions are far larger than in the twentieth century where the problems were *"local and linear"*. He claims that *complexity science* will be one of the most important sciences to understand these challenges. The term complexity science was introduced by Anderson in 1972 [23], and he has later defined complexity science to be:

> *"(..)the search for general concepts, principles and methods for dealing with systems which are so large and intricate that they show autonomous behavior which is not just reducible to the properties of the parts of which they are made"* [24].

He describes the developing discussion within physics science, where physics science has been subject to reductionism, in trying to reduce complexity to simplicity

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[1] Self-navigating vessels refers to the development of vessels that are able to follow a pre-defined route and have a capability to detect and avoid obstacles en route.

by explaining the construction of the universe in smaller and smaller entities. This traditional modelling of decomposition into structural elements has been challenged for a time and Rasmussen [25] described the problem of reductionism by *"all work situations leave many degrees of freedom to the actors for choice of means and time for action"* and argued for a functional abstraction on a higher level rather than structural decomposition. Anderson [24] states that there is a growing interest to develop complexity out of simplicity. The new perspective highlights the importance of *emergent properties,* where emergence implies that there are new properties that did not pre-exist or were expected or pre-programmed in the system. Safety could be regarded as an emergent property, and safety is created from the interaction of system components [26]. This means that we need to understand and identify emergent properties to assess safety in complex socio-technical systems. When safety is an emergent property in complex socio-technical systems it is necessary to understand what affects safety in other terms than a traditional reductionist perspective. Since the complexity in socio-technical systems leads to gradually more intractable systems and work environments, it is stated that *performance variability* is a prerequisite for functioning systems [27]. It is especially important to study humans at work to understand the nature of performance variability, with the intention not to limit by constraining how people work, but by addressing reasons for variability, identifying ways to monitor variability and understanding consequences and means to control variability [28].

A fundamental change in how the maritime industry assesses safety is needed, considering the increased complexity. The immediate risk is that we choose an approach which limits the focus to the individual vessel alone. We could measure safety based on an assessment of technical components or isolated processes and by verifying that they are covered by an autonomous solution. Such an approach tends to use traditional risk assessment methods, but is a reductionist approach which does not take the whole system into consideration [29, 30]. A limited focus on the vessel alone could result in the conclusion that autonomy is as safe, or safer, than shipping is today. This may not be a correct safety assessment from a systems perspective, since vessels do not operate as single standalone vessels. A safety assessment needs to be elevated from the perspective of a single vessel (as a sub-system in a system) to an assessment of safety in a both a system and a system-of-systems perspective where the vessel interacts with other vessels, with Vessel Traffic Service Centres (VTS), with marine pilots and several other systems in the maritime industry as well as systems from other industries. Only by using this perspective, it will be possible to discuss safety as an *emergent property,* and find out more about what affects *performance variability* due to changes in the system.

Sheridan's statement *"overall design of large–scale human-automation systems (for example, design of modern airplanes or air traffic systems) will continue to be a matter mostly of experience, art, and iterative trial and error"* [31], indicates that there are difficulties in identifying challenges in novel systems. However, we must acknowledge the importance of emergent properties, and especially the ability to amplify positive performance variability and reduce negative performance variability. In recent years several systemic safety models have gained interest such as Functional Resonance Analysis Model (FRAM) [32], Systemic Theoretic Accident Models (STAMP) [26], AcciMap [25] and EAST broken-links approach [30]. The systemic safety models aim to address the limitations of more traditional cause-effect chain models, which focus on blame and tend to search for single root causes after accidents. Systemic safety models create models that consider the entire socio-technical system, and relationships between parts of the system [26]. This paper will not elaborate on which systemic models are best suited for considering complexity in maritime operations with increased autonomy, but as all of them have a holistic approach to safety, they could all be candidates for assessing safety in designing novel systems.

The ownership of the challenge of assessing safety in a system perspective is not obvious. It remains to be seen if, and how, IMO, governmental authorities, shipping companies, technology groups or other stakeholders assume the responsibility to select methods with which to choose a systemic safety approach. Taking this responsibility implies performing large-scale testing and identifying new agents and interactions to assess safety. The other option, which is not sustainable and should be avoided, is to take the easy way out; concentrating on sub-systems and components and assuming there are no other solutions available.

3.2 Humans Will Be in the Loop, but There Will Be New Loops

Increased autonomy in navigation will impact the role of the master and will be a paradigm shift in maritime industry. To change the role of the master constitutes a drastic change to the maritime industry, not only in how to operate, but also regarding internal responsibilities for the state of the vessel, and external responsibilities towards other actors in the industry and society. A hasty and simplified approach to understanding the consequences of changing this role, could fail to uncover important aspects that affect safety, as the role of the master has a long tradition and includes many formal and informal tasks.

Autonomy aims to reduce human presence in dangerous and hostile environments, but in the maritime industry as for most of the other industries, this does not imply a total removal of humans in the system. Autonomy in the navigation function would most likely lead to relocating the humans from the bridge to a position on shore, and it is important to understand which role humans will have in such new systems.

When designing new concepts it is essential to understand *why* we need humans in the (new) loop. To create this understanding, we suggest using the terms *strategic*, *tactical* and *operational* levels to describe types of decisions in the system and where to expect change. The three terms do not have unified definitions but were initially introduced in the military literature [33]. Today they are widely used, for instance in on-road automated system development [10] where they are based on behavioural models and generalised to the problem solving task of the driver on three levels (strategical, tactical and operational) of skill and control [34]. Discussing maritime specific characteristics on each level could be a step towards understanding the human role in future maritime systems. The literature does not concur on the order of *tactical* and *operational* level, but in military doctrine the tactical level is often referred to as the lowest level of operation and operational level is the mid-level [35, 36]. In the Contextual Control Model Hollnagel describes the strategic level as being focused on the high-level goals, and is followed by the tactical level of beyond the present [37].

Coherent with this model, the paper choose to define the tactical level as subordinate to the strategic level.

> Strategic level:
> *Strategic decisions set objectives for the organization as a whole, relatively long-range objectives, and formulate policies and principles intended to govern selection of means by which the objectives specified are to be pursued.* [33]. Strategic decisions would fall under the three dimensions Boy [22] describe as important for an organisation; safety, efficiency and comfort.
> Tactical level:
> The tactical level could be described as the criteria derived from the goals set at the strategic level [34]. In navigation this would be both long-term and short-term planning on how to act, such as planning and deciding on the route, or weather routing during the voyage.
> Operational level:
> The operational level is the imminent response within strategic and tactical boundaries to occurring events. In navigation this would be the choice of whether to alter speed or heading in response to the immediate surroundings.

As illustrated initially in this article, autonomy is difficult to describe as a state-of-being. Since autonomy is a process of change, the role humans will play in the system will also change over time. However, the change of the role of humans is initially expected to occur mainly on the *operational* level, to a lesser extent on the tactical level and is not expected to affect the strategic level. The main reason for this expectation is based on the acknowledgement of maritime socio-technical systems being intractable and such systems work because people are able to adjust what they do [27, 38]. In particular this applies to managing the constant trade-off between objectives on the strategic and tactical levels, for example the balance between safety and efficiency, which is an area where humans are still superior to technology [27]. The prediction that change will occur mainly on the operational level will probably change, and a natural development would be that a successful implementation of increased autonomy on the operational level triggers an investigation of possible benefits of autonomy on the tactical level.

We do know that there will be humans in the loop, and even though the operational level will gain more autonomy, there will still be humans to take strategic and tactical decisions. *Why* we need humans in the new loops is fundamental to the understanding of the importance of taking humans into account in the entire concept design.

3.3 Humans Will Be Responsible and Will Remain in Control

The final challenge presented in this paper is to create an understanding of *how* the humans should be involved and kept in the loop. The similarities between automation and autonomy are many, and one similarity is the challenge of how to optimize the sharing of functions between humans and technology based on human strengths and weaknesses. In systems engineering a function refers to *“a specific or discrete action (or series of actions) that is necessary to achieve a given objective*” [3]. These functions are derived from the system requirements in a hierarchy where top-level functions are broken down to second-level functions and further to lower level functions. In the conceptual phase of systems design the purpose is to develop a top-level system architecture and initially to identify *what* needs to be accomplished, and less focus is put on how to accomplish it [3].

A widespread concept in Human-Automation Interaction (HAI) is to combine Levels of Automation (LOA) with *function allocation* which uses a four-stage model of HAI; information acquisition, information analysis, decision selection and action implementation [39]. Each of these four stages is described in a continuum (the Levels of Automation) ranging from no technological involvement to a complete technological ownership. The concept is criticized for not taking into account the complexity of operating environments which leads to imprecise and unreliable predictions, which again leads to a concept which is difficult to apply in practice [40]. There is an on-going discussion between the defenders of the concept and those who challenge the concept. Both sides seem to agree that there are weaknesses such as difficulties in predicting human behaviour and imprecise behavioural constructs, and that there is a need for a more concise operational definition of the concept [9, 40, 41]. The solution to the problem is more contested, in that the defenders of the concept are suggesting an evolution of the model to get a more accurate and precise prediction of human-automation system performance [9], and the opponents are suggesting to leave the LOA paradigm entirely [40].

Those involved in the development of autonomy in the maritime industry need to pay attention to the limitations of the existing models, and the on-going debate on proposed solutions. A mutual agreement on a best practice to describe interactions between human and technology does not exist, which be a challenge for the practitioners that are designing novel systems with increased autonomy.

Bearing in mind the first challenge in this paper which argues for a holistic approach rather than a reductionist approach, it will not be beneficial to aim for complete functional allocation. There is a need to search for solutions that encompass complexity and a need for development of more dynamic models of HAI. A possible first step that does not contradict neither the defenders nor the opponents of the concept of LOA and function allocation could be to identify the system's top-functions, and then move on to exploring the human role in the top-function in terms of responsibility, authority and control.

Navigation could be a top-level function, and the discussion could start with exploring the responsibility, authority and control within this function. Amy R. Pritchett describes the relationship between responsibility and authority as *"authority is generally used to describe who is assigned the execution of a function in operational sense, responsibility identifies who will be held accountable in an organizational and legal sense for the outcome"* [42]. Execution in this definition is presumed to include all four stages from information acquisition to action implementation, and is not solely linked to the action implementation.

Control does not, as many of the other terms in this paper, fall under a uniform definition. Like the term autonomy, the Society of Automotive Engineers has placed the term control in their section of deprecated terms in their recommended practice. The reason is that the term has numerous meanings in technical, legal and popular language [10]. Taking a systems perspective, Leveson [43] states *that "control processes operate between levels to control the processes at lower level in the hierarchy. These control processes enforce the safety constraints for which the control process is responsible".*

Control is linked to both responsibility and authority, and control is the process where the *responsible* agent of the function ensures that the agent with given *authority* executes its function in accordance with the system's requirement (see Fig. 1).

SARUMS *"methods of control"* describes the relationship between human and vessel ranging from method 1 which is "Operated" (remote control, tele-operation or manual operation), to method 5 which is "Autonomous" [44, 45]. The *"methods of control*" are a valuable contribution to create a more accurate characterisation of control, however the approach is not the best fitted for discussing how humans will be involved in future systems with increased autonomy. The responsible agent of a top-function needs to ensure that the system's requirements, decided on the strategic level, are translated to safety constraints that then are complied with on the operational level. Both responsibility and control will, at least for the near future, be allocated to humans, and hence *methods of control* should be defined from the perspective of the *humans* rather than the *vessel*.

This perspective should be explored in depth, since even though most of the published documents of maritime autonomy address some human interaction, it is predominantly discussed from the perspective of the vessel. Scoping a system based on responsibility, authority and control from the *human perspective* will bring the human into a central role, and pave the way for a human-centred design approach.

A human perspective on *authority* will take into account the challenges of humans directly involved as "executor" but from a position on shore (e.g for remote operated vessels, or intervening if a self-navigating vessel is out of its constraints). The authority sharing will include many of the traditional challenges in HAI, which includes the discussion of what and how to share functions between human and technology.

A human perspective on *methods of control* will be able to describe different types of control to ensure that the function is executed in accordance with the system's requirement and human capabilities. The different methods of control will experience different challenges that the system needs to take into account. Examples of methods of control could be direct involvement (combined role with authority), monitoring (continuously assessing the executor's decisions) or supervising (intermittently assessing the executor's decisions). However, these methods of controls are simplified, and the best fitted methods of control for maritime autonomy should be further explored.

A human perspective on *responsibility* will discuss which responsibilities are linked to the top-function, and if there are areas of responsibility that are not accounted for in a new concept. It will contribute to the discussion of competencies and legal accountability, and it will be important for designing a concept that could be approved by authorities.

Further, it is important that we encounter for internal and external variations in the system. In practice, this means that we cannot develop a static concept with *one* agent given authority to execute and choose *one* method of control. In navigation of a vessel we will see different requirements in congested waters than in open waters. The terminology we use needs to be able to describe a dynamic concept, and handle the complexity that follows with changing authority and methods of control during an operation.

How the humans are involved will change, and we will see that technical agents will be given more authority to execute functions. However, humans will remain

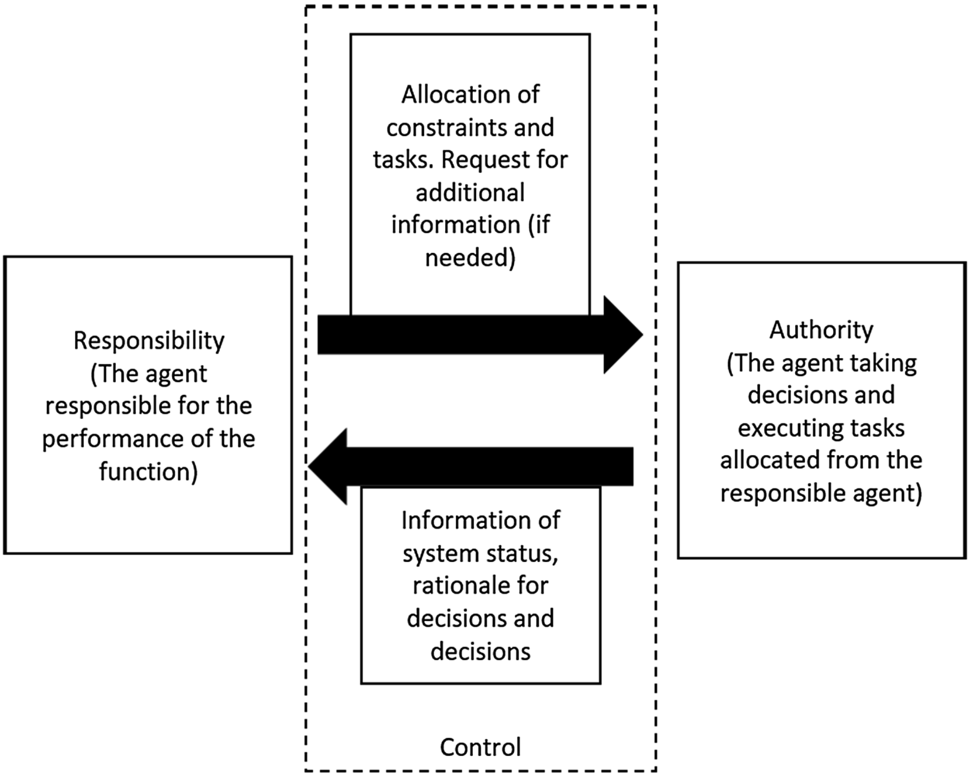

Fig. 1. Control links the responsibility and authority

responsible and humans will remain in control. It is therefore imperative that we develop a terminology that is best fitted to describe responsibility, control and authority from the human perspective. The way humans will be involved in future autonomous operation leads to new challenges, and these challenges need to be overcome to prove the safety status of novel system.

4 Conclusion

The increasing interest in autonomy in transport segments is also present in the maritime industry. Even though it is gaining a lot of attention, there is no unified definition of what autonomy is. This paper argues that agreeing on a defined state of being for autonomy would not be possible, and focuses on the autonomy as *a process of change*. As for automation, autonomy is about how to increase the use of machine agents in functionalities previously done by humans. The use of levels of autonomy as a state of being would be imprecise since what is defined as a high level of autonomy today (as self-navigating vessels monitored from shore) will be a lower level of autonomy in few years (if the machine agents are replacing humans on shore). This perspective acknowledges that autonomy is different from system to system, and will vary over time and be affected by the context. The purpose of changing the focus from a state of being to a change process is to learn from many aspects of autonomy and allow for different factors based on context and previous state of the system.

The paper discusses the importance of considering humans in the development of autonomy in three areas concerning the safety of the navigation function. The first area is to leave the traditional safety approach, where systems are reduced to components and these components are assessed in isolation. The paper argues for a systemic approach to safety with a holistic perspective, where safety is an emergent property of the system, and human performance variability is essential for improving safety.

The second area is to understand why there will be humans in the new loops of systems with increased autonomy. The paper uses the levels strategic, tactical and operational to argue that autonomy would initially be experienced on the operational level, while the human ability to perform trade-offs between strategic and tactical objectives is still superior to the technology. System designers need to understand the importance of humans in the loop of future systems.

The third area is to know how to involve humans in the system, and for system designers it will be essential to follow the on-going discussion of the validity of the concept of function allocation and levels of automation to describe HAI. Both improving the concept and leaving the concept will lead to major implications within HAI. Independently of this discussion the paper argues for taking a human perspective on responsibility, authority and control of the top-function, such as navigation. As humans will be involved in the loop, at least on tactical and strategic levels, they will also be responsible and be involved in control processes of the execution of function, and the paper highlights the importance of developing *methods of control* from the human perspectives in the development of autonomy in the maritime industry.

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Paper II

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How vessel traffic service operators cope with complexity – only human performance absorbs human performance

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Paper III

A socio-technical perspective on the future Vessel Traffic Services

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Abstract. Autonomy is expected to cause significant changes to the Maritime Traffic System (MTS). The Vessel Traffic Services (VTS) is a control system in the MTS and will be affected by new interactions caused by autonomy. The paper proposes a proactive approach in discussing the future VTS. The paper renders the historical development of socio-technical systems theory and argues for systemic evaluation of internal and external consequences of changes in the design of the future VTS. A democratic process to involve people from the various levels of the VTS organisation with different competencies is suggested. To evaluate the consequences of change, a systemic internal and external approach is suggested. For discussing internal consequences, a levelled socio-technical systems model is adapted and applied. External consequences are suggested to be discussed by applying design principles of system-of-systems to understand the interplay between VTS and the MTS.

Keywords: Vessel Traffic Services (VTS), Maritime Traffic System (MTS), socio-technical systems, autonomy

1 Introduction

The maritime industry is expected to face major changes in the coming decades. Technology 4.0, referring to the large-scale interconnection of components, systems and infrastructure (1), affects existing services and opens for new types of services. Autonomous concepts are believed to become a reality as emphasized by the International Maritime Organisation's (IMO) regulatory scoping exercise for Maritime Autonomous Surface Ships (MASS) (2). Exactly how these concepts will be realised is still uncertain. The concept closest in time to become a reality is the container vessel Yara Birkeland, planned to go into service with shipboard personnel in 2020 and gradually move to autonomous operation by 2022 (3). Additionally, tests with a self-driving ferry in Finland (4) and a remotely operated tug in Denmark (5) have been conducted, and small passenger ferries to replace bridges are planned (6,7).

A future with autonomous vessels will change the maritime industry in many ways. However, the change is not merely about the autonomous vessel itself. It is also about how it will interact with other actors in the Maritime Traffic System (MTS). One important measure for navigational safety in the MTS is the use of Vessel Traffic Services (VTS) to guide and advise the traffic (8). The VTS is described as a control system in the MTS with interactions within the system (the VTS) and externally with the systems in its environment (9). A future MTS with autonomous vessels will consequently cause changes for the VTS, particularly for the external interactions between conventional and autonomous vessels.

It is possible to approach the discussion of future VTS in two ways, one is reactive, and the other is proactive. The reactive approach is to take a stance that autonomy needs to be developed so it has the same capabilities as conventional vessels. The convenient consequence for the VTS is business as usual, and it is up to the ship designers to solve the challenge of designing technical solutions that respond as a human navigator would do. The proactive approach is to take ownership to the overall objectives of the MTS to be as safe and efficient as possible. However, such an approach is a complex task, since it comes with a requirement to jointly consider the VTS and the MTS. A joint consideration makes it impossible to understand the actors in the system in isolation but requires a holistic approach. This paper suggests that the proactive approach is challenging but necessary, and argues this approach requires consideration from researchers in the maritime industry.

The paper considers the VTS as a socio-technical system (9,10) and explores how a systems perspective and the use of a socio-technical systems approach could guide the early phase of designing the future VTS. The paper aims to answer the following research question:

> *How can a socio-technical systems approach focusing on a democratic process, and systemic evaluation of internal and external consequences, be used in the early design phase of the future VTS?*

2 Background

The regulatory scoping exercise for Maritime Autonomous Surface Ship (MASS) by the International Maritime Organisation (IMO) (2) is a manifestation of the belief of autonomy being important for the future maritime industry. The IMO suggests different degrees of autonomy which are determined by the locus of control of the vessel (ship/shore) and by whether there are seafarers on board or not. In other transport segments, it is suggested not to use the term autonomy, since it is heavily dependent on the opposite of the original meaning of the word, namely communication and/or cooperation (11). The term levels of automation (LOA) has been used to describe the relationship between human control and machine control (12). In the perspective of LOA, the highest level of automation has been described as the computer decides everything, acts autonomously and ignoring humans (13). Hence, autonomy being a level of automation. The paper will consider autonomy as a process where the use of technology implies a significant change to the system's human and technology function allocation (14). Such an approach acknowledges that autonomy could be different from system to system and opens for many different concepts that all could cause major changes in the maritime industry, however, we expect autonomous systems to be able to collaborate with other maritime systems.

2.1 Vessel Traffic Services

The Vessel Traffic Services is one of the measures to meet the governmental responsibility of the safety of navigation and regulation of maritime traffic in maritime waters stated in the United Nations Conventions on the Law of the Sea (UNCLOS) (15). The IMO is responsible for adopting international shipping rules and standards, while the individual nations have jurisdiction for their territorial waters and nominate a Competent Authority responsible for implementing the VTS. International Non-Governmental Organisations (NGO) are a substantial contributor for IMO, and the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) is the NGO closest associated with the development of the VTS (8).

For Norwegian waters, the government executes the responsibility through the Ministry of Transportation. The Competent Authority is the Norwegian Coastal Administration (NCA), hence being responsible for personnel, equipment, facilities, procedures, finance and legal matters (8). There are five VTS centres, four responsible for territorial waters and one for international waters. In addition, Traffic Separation Schemes (TSS) are established for transit traffic in international waters and in two of the most congested traffic areas in territorial waters (16). The individual VTS centres are responsible for everyday activities and in addition responsible for adapting the centrally developed procedures to local procedures valid for their area.

2.2 The Maritime Traffic System

To evaluate changes to the MTS, it is necessary to clarify what is included in the term. The MTS is context-dependent; it will change from one geographical location to another and change over time. The paper discusses the role of VTS, hence, the context is that the VTS is involved in territorial waters where one state has jurisdiction. The term stakeholder is commonly used in systems engineering to identify groups or individuals who affect, or being affected by, the achievement of an organisation's objectives (17). To identify the MTS, systems or stakeholders that affect, or being affected by, the achievement of *safe navigation* is included.

Van Westrenen and Praetorius (18) state that control in maritime traffic is exercised by the bridge team, pilot and VTS. Mansson, Lützhöft and Brooks (19) describe key participants in navigating and manoeuvring ships in port waters to be the shipmaster, maritime pilot, tug master and the VTS-operator (VTSO). Fiaz (20) has analysed stakeholders for navigation and assessed their impact on safety and efficiency. He identified that shipowners, crew, water canals/coastal waters/straits, IMO, Flag State, Classification societies and educational institute/guideline publisher influence safety.

In sum, for the MTS the interaction between bridge team, pilot and VTS is imperative. However, this interaction is likely to be affected by the organisational context, such as identified in the stakeholder analysis where shipowners are mentioned. Consequently, one can assume both pilot organisations and Competent Authorities (for the VTS) being important. There are also several other actors such as IMO, Flag States, Classification societies, educational institutes, and guideline publishers in the stakeholder analysis. The MTS, therefore, consists of the immediate interaction between the operators involved in navigation in the area, and additionally, the organisations and stakeholders affecting their decisions. An example of a future MTS is shown in **Fig. 1**.

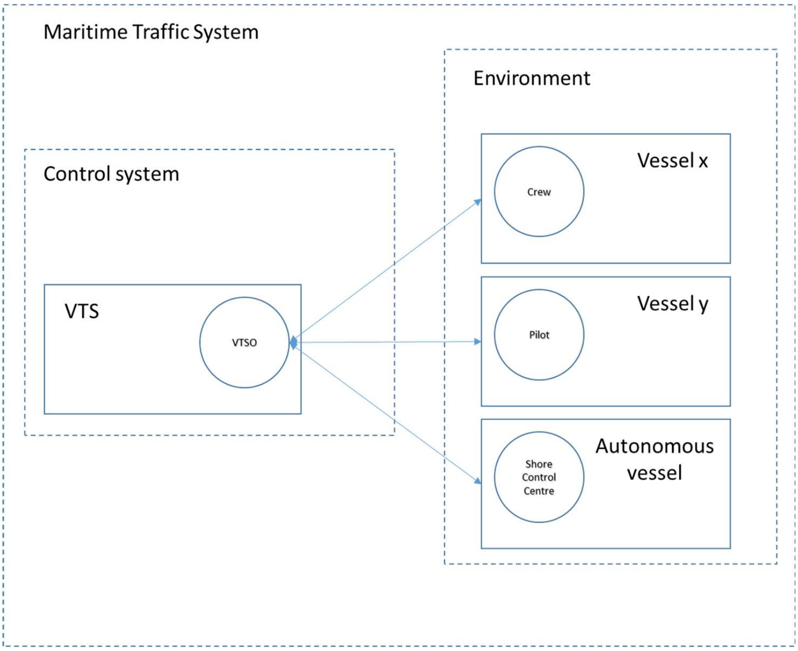

Fig. 1. The Maritime Traffic System (MTS) described as of the vessels in the area (the environment) and the VTS as the control system.

3 Theoretical frame of reference

The share of autonomy will be imperceptible for many years since the great majority of vessels will be conventional. However, in some areas, autonomous vessels will have a significant impact on the traffic situation. In these areas, the autonomous vessels will coexist with conventional vessels. Such coexistence implies new interactions between the actors in the industry. To explain the implications of the coexistence in the industry systems theory is applied. The doctrine of expansionism considering objects as a part of the whole is a cornerstone of system theory (21), and the paper presents relevant theory to explain a holistic picture of the relationship between the actors in the industry. Initially, the taxonomic distinction between systems and system-of-systems is presented. Further, the development of socio-technical systems theory that origins from the systems theory is presented.

3.1 System-of-systems

More than 50 years ago Ackoff (22) pointed to the fact that the systems concept lacks a unified set of terms, ironically lacking a *system* for the terms in systems science. Consequently, he presents a comprehensive list of terms, where a system is defined as a set of interrelated elements. Further, he defines an organisation as *a purposeful system that contains at least two purposeful elements which have a common purpose relative to which the system has a functional division of labour* (22). He differs organisations from organisms by stating that the organisms do not contain purposeful elements, and none of the organisms can display will (22). The clarification of terms by Ackoff is important and points to a difference between focusing on an organisation and an organism. It implies a difference between what could be a component in a system and what is a system. However, by zooming out to *more* than one organisation, collaboration and, at least partly, common goals between various organisations is found. Large scale, complex, socio-technical systems (such as organisations) that collaborate are often named system-of-systems, even though not all socio-technical systems are systems-of-systems (23). Similar to Ackoff's abovementioned challenge about terms for systems, there is no widely accepted definition of system-of-systems.

Maier (24) aims to create a distinction between a system and a system-of-systems. He suggests *operational* and *managerial* independence of system components could be used for creating a taxonomic distinction between systems and system-of-systems. Further, he emphasizes that the system must pass both the criteria of operational and managerial independence to be categorised as a system-of-systems. Being independent and at the same time being a system-of-systems could seem contradictory, however; Maier explains that the criteria are to be used for collaboratively integrated systems (24). He does not explicitly define what *collaboratively integrated* means, but he states that collaborative is opposed to directed, and the decision to collaborate is an on-going discussion, further, he uses the synonym 'federated system' (24). Hence, it is possible to conclude that the systems have some common goals, and the systems see a positive effect of collaborating with other systems.

The operational independence considers that if a system-of-systems is disassembled, the component systems *can* operate independently to fulfil their own purposes and they are able to fulfil purposes on their own. Managerial independence considers that component systems *do* operate independently, and even if being integrated in a superset system, they continue their operational existence independent of the system-of-systems.

An important contribution of Maier's work on differentiating systems and system-of-systems, is his work on defining successful design criteria. The independent properties of system-of-systems require a different mindset for the design. Maier suggests designers of system-of-systems need to follow the design principles of *policy triage* (choosing what to control), *leverage at the interface* (between the component systems), *stable intermediate forms* (stability in the time period before the system-of-systems is finalised), and *ensuring cooperation* (voluntary cooperation through incentives) (24).

3.2 Socio-technical systems

The term socio-technical systems origins from the Tavistock Institute research program in the 1950s where the separate approach to either social or technical system was not seen as sufficient. A new approach where organisations were envisaged as socio-technical rather than either social or technical emerged (25). At present, the socio-technical theory is broadly acknowledged to refer to the joint optimisation between social and technical factors (26,27).

Quality of work-life and democratic processes. In the period until the late 1970s, the interest in socio-technical systems theory increased and socio-technical principles were defined to design systems with 'quality of working life' as the desired emergent property (26,28). The Scandinavian countries were pioneering the initiation of socio-technical design by legislating the cooperation between management and workforce, with emphasis on employees to participate in all levels of decision making. Several democratisation projects were initiated and the mindset on humanisation was a significant contributor for the laws on working conditions. The development did not come through without resistance, and in general two types of resistance were experienced. First, a common belief was that any management-initiated change must be for the worse. Second, some engineers and technologists perceived changes to threaten their position and status. Additionally, some unions were negative intintroducing socio-technical principles since this could threaten their power and influence (26). Despite these obstacles, the democratic process and the humanisation of the work situation became important aspects associated with socio-technical systems.

Automation and complexity. During the 1980s the situation for the industry changed drastically and could have become the dark ages of socio-technical theory. From having problems getting enough staff, the increased use of technology reduced the need for workforce. Consequently, one of the main motivations for designing systems for the quality of working life diminished. The new focal point was cost-cutting, and the industry looked to lean production principles where standardisation of work processes stood opposed to the socio-technical systems principles of decentralised control and coordination. Socio-technical systems thinking lost its strong foothold, and the remaining expertise was found in dispersed, small groups (26). Several large accidents in the second half of the 1980s heavily affected the understanding of causes for accidents. The accidents Chernobyl (1986), Challenger (1986), Zeebrugge (1987) and Dryden (1989) shifted the focus from human errors to organisational factors. Even though Robinson (29) argued for socio-technical systems principles could provide a design tool for safety problems already in the beginning of 1980s, the accidents regenerated the socio-technical systems theory's relevance for safety almost a decade later (30). The interest for organisational causes transferred to cognitive science and human factors and moved these fields closer to the socio-technical field. Literature from organisational psychology from the 1950s influenced new methods and understanding the context became an important aspect (31). Where the focus of cognitive science had been on the individual, the unit of analysis now shifted, and methods considering human and context together (Distributed Cognition (DC)) (32), or human(s) and technology in coagency (Cognitive Systems Engineering (CSE) and Joint Cognitive Systems) (33), emerged. A different challenge also caught attention in the aftermath of the disastrous accidents in the late 80s; systems were becoming increasingly more complex. The interdependence between system components, and between the system and environment, created unanticipated outcomes. Theories such as Normal Accident Theory (explaining accidents as inevitable due to complexity) (34) and High Reliability Organisations (defining characteristics of organisations coping with complexity) (35) became prominent in the safety discussion. Complexity was incorporated in socio-technical systems thinking, and the term *complex socio-technical system* was used and dimensions for such complexity defined (36). Such development was reflected when the socio-technical systems principles were revisited in 1987; both gathering and analysing data from users were highlighted (37) in the revised version.

Thinking in levels. In the period from the mid-80s to the new millennium, cognitive science, human factors and socio-technical system theory blended and developed the foundation for the new ways of safety thinking. Organisations, as being socio-technical systems, differed between active failures (in the sharp end) and latent conditions (in the organisations), and applied barriers to prevent accidents by managing the risks (38).

Towards the end of the 90s a significant perspective of socio-technical systems theory gained interest; in addition to understanding the system in context, the socio-technical system needed to be understood in levels or layers (36,39). This way of considering the socio-technical system was first presented by Trist who presented an evolution from an initial focus on the *primary work station*, *to whole organisation systems*, and last at the *macrosocial level* (25). The need to engineer for safety, led to a focus between the human and organisation, a concept building on cybernetics where the dynamic communication within systems is emphasised (40). In line with this, an important perspective for the development of socio-technical systems the last 20 years has been Rasmussen's criticism of the research on socio-technical systems being studied separately by individual disciplines and concentrated at one level of the system. **Fig. 2** presents Rasmussen's socio-technical system at levels (from operation (bottom level) to top level): *work, staff, management, company, regulators/associations*, and *government*. Further, Rasmussen (41) argued for cross-disciplinary studies vertically across the different levels of socio-technical systems.

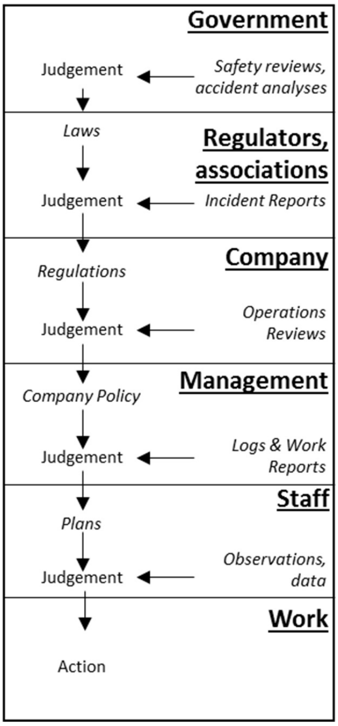

Fig. 2. Rasmussen levels of socio-technical systems (39)

Interdepecincies and involving users in design. The socio-technical principles were revised for the third time by Clegg in 2000, motivated by the disappointing performance of technology itself and management practices in the development and implementation of new technologies (42). The revised socio-technical principles aimed to again bring the social and technical together to an interdependent aspect of the work system. Clegg (43) pointed to organisations lack an integrated approach to technical and organisational changes, and that users do not have enough influence on system development. The revised set of principles intent was to contribute to *design* new systems, rather than only to *understand* the human and organisational impact of new technologies (42).

System accident models and resilience. Apparently, the socio-technical systems theory in the field of design of complex systems has made a strong comeback after the moderate interest in the 1980s, and responds to organisations need for being adaptable, flexible, responsive and resilient (44). The perspective of levelled socio-technical systems has been the basis for a system perspective of the performance of organisations. Particularly to understand and learn from accidents, this way of thinking has been prominent since 2000. Accident models such as STAMP (45), AcciMap (46), HFACS (47) have all applied the levelled perspective to move the focus from human error as the cause of an accident to organisational causes. A different, more proactive, application of socio-technical systems thinking is found in resilience engineering. The resilience perspective is focused on how the socio-technical system sustains required functioning in a variety of operation conditions by highlighting how to succeed (rather than fail) by adapting the performance to the environment (9,48).

4 A socio-technical approach to the future VTS

The principles of socio-technical systems theory have been revisited over the last 60 years. From the focus on quality of work-life to focus on system safety, and in the later years a call for socio-technical systems thinking proactively in systems design. Many of the leading methods for assessing safety in complex systems (e.g STAMP, FRAM, HFACS), based on systems theory, share the theoretical framework as socio-technical systems theory. These methods take the necessary systemic perspective that explores the relationships between causal factors within the systems and addresses the complexity known to be important for improving safety in modern organisations (45,49,50). On the other hand, the methods share a challenge of being time-consuming to apply, resource-intensive, and often relying on detailed and high-qualitative data (45,49–51). When designing future systems, the detail level is low and the uncertainty high. Consequently, it is difficult to apply such systemic safety models to support the initial design phase. The comprehensiveness of the methods could, therefore, become a barrier that leads to them not being used before design solutions are chosen. In turn, this shows that the methods might not be the right answer to Clegg's call for including users in the design phase (42). The following section presents a simplified approach to the discussion of the future VTS. It argues that a *democratic* process and a *systemic* evaluation of internal and external consequences of changes reflects a socio-technical systems approach in the early design phase of the future VTS.

4.1 Identifying the future role of the VTS is a democratic process

A democratic focus on the workforce has been a cornerstone in socio-technical systems theory. The democratic focus includes different aspects of emphasising the workers in the organisations. In the early phase of socio-technical thinking, by aiming for humanisation of the work situation, the employees were included to determine the required quality of work life (26). Later, the democratic focus was mainly about *understanding* cognitive activities in man-machine systems (52) and human performance in light of latent conditions (38). *User involvement* has been emphasised to design systems that are capable of self-modification (28), where both *technical and social experts* are needed for joint optimisation (37). User involvement from *all levels of decision-making* (26) and being open for *consulting and informing colleagues* (28) have been underlined as being necessary. Not only to understand socio-technical systems, but also in the *design* of such systems by involving the *responsible for manage, use and support* of the new system (42).

The development of socio-technical systems theory has shown several different aspects to why the democratic process is needed. To identify the future role of the VTS, it is necessary to initiate a democratic process where these aspects are understood and implemented.

The first step is to involve the VTS-organisation in the design phase. It is necessary to come back to the potential technology development in the MTS, and the present attention to autonomous vessels. In this development, the VTS could be a reactive system component that adapts its behaviour to the emerging requirements caused by new technology. The other option is to take a stance that the VTS could contribute to a safe and efficient MTS by a proactive approach focusing a joint optimisation between the VTS and the other system components. Hence, the involvement of the VTS organisation by anchoring the need for discussing the future role of the VTS is the first step.

The second step is to nominate users to be a part of the design process. Implicit in the socio-technical term, both technical and social expert knowledge is needed. As experts in an organisation do not come from either a technical silo or an operational silo, it is necessary to find a strategy to select people with knowledge from various expert areas in the organisation. The selection strategy should also warrant ownership, and people responsible for managing, using, and supporting the future system should be selected. There are several levels in the organisation that manages the VTS (see discussion of internal effects), and the selection of users should be representative for the various levels. The users of the future VTS could be represented as the VTS-operators. However, all VTS-operators should not be put in the same category. As an example, some operators could be more interested in technical solutions and functionalities, while others have their interest in concept development. Consequently, such variety should be reflected when selecting users. The support of the future VTS could be both administrative and technical personnel, and representatives for the support element need to be included. A common quality of all the involved personnel is that they need to be open to communicating and consulting colleagues about assessments from the design phase.

The abovementioned two steps aim to find the people from the organisation with the ‘correct’ expert knowledge from the different levels in the organisation, with ownership to the design process and being open for sharing and discussing with colleagues. There is no recipe for exactly how to reach such a goal. However, good cooperation between internal organisational expertise and expertise about socio-technical systems theory could be considered beneficial. The internal expertise of the VTS-organisation will provide knowledge about the organisational structure, areas of expertise, and persons with different areas of interest. Expertise in socio-technical expertise could guide the selection process, so no expert areas are over-emphasised. Further, such expertise could make sure that the various aspects of the socio-technical democratic process are understood, and consequently, reduce the risk of just putting some people together and start discussing.

4.2 A systemic approach evaluating internal and external effects

The systems perspective as a foundation for the socio-technical systems theory points to the interactions within the system and between systems. The VTS is a part of the MTS, and as such interconnected with the other component systems. As such, deciding on the future role of the VTS will affect the other systems in the MTS. To understand the interplay between VTS design and the MTS design is therefore crucial. However, as the types and number of interconnections could be infinite, it is necessary to limit what to assess in evaluating how the future VTS would affect the MTS. The following section presents how the use of system-of-systems design principles could guide the discussion of the interplay between VTS and MTS.

Consequently, internal effects for designing the future VTS are important. The perspective in system safety models highlights the connection between the operator and the rest of the organisation. In the last section, a broader perspective on implications for future VTS is suggested, and an adapted version of Rasmussen’s levels of socio-technical system is used as a framework for the discussion.

4.2.1 The interplay between MTS design and VTS design

As presented in the background, there is no static MTS. However, the bridge personnel, VTS-operators, and pilots could be considered components of the system. Additionally, the parent organisations of these operators and more distinct actors affect the system. In sum, these components collaborate to achieve a safe and efficient traffic flow, and they are integrated through rules, regulations, and communication. Consequently, one could argue that the MTS is a collaborative and integrated system. The next question is if the MTS is a system or a system-of-systems. Following Maier’s (24) taxonomy the components need to be operationally independent and managerial independent of each other to be a system-of-systems. Maier has evaluated the system-of-systems properties of an Intelligent Transport System (ITS) (53) and the similarities to the MTS could guide the assessment.

To decide if the component systems are managerial independent, an evaluation of the components being acquired and operated independently is needed. Shipping companies are owned and run by a variety of actors, and these are most certainly independent of each other. The VTS and pilot service are normally managed by the government, and to a certain degree have some common management. However, in sum, the component systems in the MTS could be stated to be managerial independent from each other. The next criterium is being operational independent. As Maier states in his evaluation of an ITS, the operation is a mixture of individual and government action. In the MTS the vessels could operate independent of each other, and potentially independent without VTS and pilots. The VTS and pilots will have no function without vessels in the area; however, it is possible to claim they are operational independent since they are not relying on another component system to function. In sum, the conclusion is that the MTS, in conformity as the ITS, is a collaborative and integrated system, and further fulfil both criteria of being a system-of-systems.

The perspective of the MTS being a system-of-systems is important in the discussion of the future VTS. The design of VTS will to a large extent affect the design of the future MTS. Consequently, the design principles for successful system-of-systems propose a solid base for discussing the interplay between VTS design and MTS design (24).

Policy triage. The most significant impact is that opposed to systems design it is not possible to fully control the configuration (e.g. traffic flow) or the evolution (e.g. design of vessels) of system-of-systems. A consequence is that even if the VTS is defined as a control system, it cannot fully control the systems in the MTS. The VTS as being a socio-technical system is *in control* when it creates a stable performance output (9,33). When designing the future VTS, it is therefore important to focus on the balance of what to try to control and what not to control, and how the VTS could contribute to a safe and efficient performance in the MTS. Maier (24) warns against over-control (will fail due to lack of authority) and under-control (will fail due to eliminating the system nature in the integrated system).

Leverage at the interfaces. Since the component systems have independent properties, the architecture of system-of-systems needs to consider the interfaces between the systems. One major change is the interface between the autonomous and conventional vessel, and it will basically be an interface between technology (autonomous vessel) and humans (conventional vessel and VTS). This will be a novel situation and requires a different way of communicating than today. The present solution to create a mutual understanding is sharing information and intentions on voice communication, and often relying on informal ways of operating. In a future MTS, it could be expected that autonomous vessel could be great at following formalised rules but poor at understanding informal ways of operating and sharing information and intentions as it is done today. Consequently, different interfaces than the traditional voice communication need to be considered, and the future VTS should consider how it could improve interfaces between future system components.

Stable intermediate forms. Intermediate stability relates to the period until a future MTS is constructed and finalised. Such an approach could be argued to be artificial since an MTS will never reach an end-state. However, *testing and evaluation*, initially as individual components and later as integrated systems (21) is important. For autonomy, this implies that the concept will be tested in parts, but later also as a component system in the MTS.

Ensuring cooperation. The systems being collaborative, and at the same time independent, leads to cooperation in the MTS being to a certain degree voluntary. The cooperation in a future MTS with autonomous vessels will to a larger degree be between unequal actors, with both conventional vessels, autonomous vessels, most likely a shore control centre and a VTS. The development needs to find the right balance where formalised rules and control of the system is considered in the light of providing enough flexibility to users.

Designing a VTS should aim for contributing to stable performance of safety and efficiency in the MTS. The design principles for systems-of-systems are applicable to the design of the MTS, and due to VTS being a control system of the MTS, also applicable for understanding the interplay between VTS solutions and the MTS.

4.2.2 The internal effects for the VTS

An important element in the systems theory is the control system that regulates the behaviour of the overall system. In the socio-technical systems theory this has been reflected since the increasing automation of the industrial processes. The role of humans changed from being directly involved in the action, to decision making and problem solving (52). Even if the technology changed and seemed to take a larger portion of the duties, the human element became more important to control processes. The understanding of the human role in relation combined with organisational causes became important. Initially, this relationship was explained linearly, with latent conditions and swiss cheese (38). Later the relationship was understood by more complex systems models with increased awareness of the multiple connections between the operator and the organisation (45,49,50).

Rasmussen's levelled model of socio-technical systems visualised and formed much of the present understanding of socio-technical systems. In the following section, it is argued that the model could be a tool in the initial design of new socio-technical systems. The democratic process previously discussed, involves personnel from the entire organisation, and the model could initially be used to make sure that all levels are represented in the process. **Fig. 3** represents a suggested visualisation of the Norwegian VTS-organisation by applying Rasmussen's model. The governmental level is defined to be the Ministry of Transportation (MoT), who is responsible for the service. Regulators and associations are both the MoT and the Norwegian Coastal Administration (NCA) since they both have responsibilities for the Harbour and Fairways Act. The company-level points to NCA and the Department of Maritime Safety. The management level is the VTS managers of the individual VTS centres. Staff is the crew on duty, and finally the work is the individual VTS-operator.

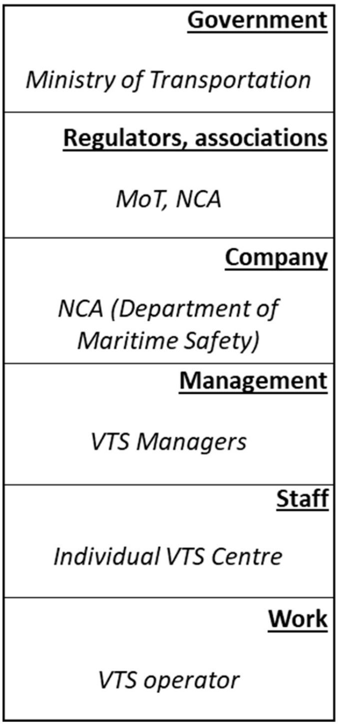

Fig. 3. The Norwegian VTS organization visualized in Rasmussen's socio-technical models

The essential step of the democratic process is to discuss potential solutions and evaluate the effects of these solutions. The complexity in discussing VTS-roles is the interplay between the VTS and the MTS as discussed in the former section. Further, the consequences for the VTS itself need to be understood. As Rasmussen highlights, the consequences are different on the various levels of the organization. As such, the future roles of the VTS should be evaluated by understanding the consequences for each of the levels in the model as shown in **Fig. 4**.

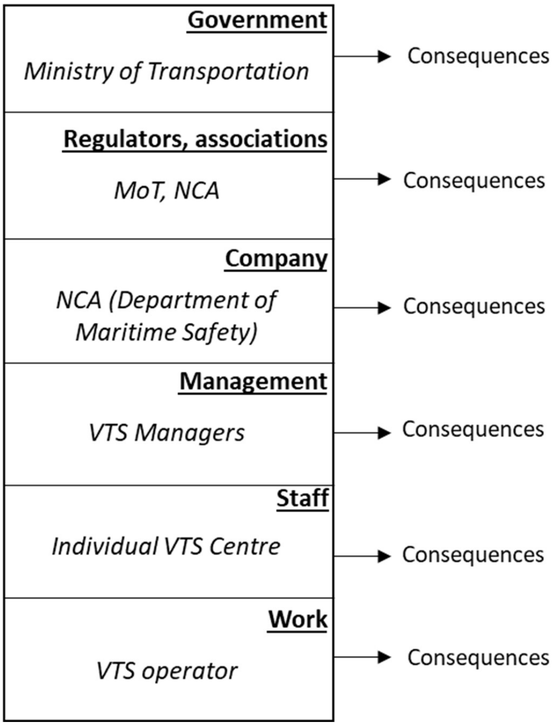

Fig. 4. The consequences of changes to the VTS should be assessed on the various socio-technical systems levels

A benefit of using the model is that it is not dependent on a high detail level. In the initial phase of designing future systems, the granularity is low, the discussion of implications might be on an overall level. However, even with a low level of detail, it is possible to identify obstacles that require attention. As an example, if autonomy calls for different interactions between vessels and VTS-operator, a change of regulations might be required. By only focusing on the VTS-operator, such changes could easily be omitted by arguing it is not possible due to regulations. However, by using the model, it is possible to keep it as an option and raise the argument of changing regulations to the regulator level.

The intention of the model is to understand interaction, *between* the levels. A risk of thinking in levels is ignoring such interaction and focus on the individual level and losing the overall objective. Hence, the process must be goal-oriented, asking what is required to meet the proposed solution. The answer will point to consequences for the levels and for the interaction.

In the initial design phase, the model could provide a good basis for discussion and deciding direction. The visualisation of the model is easy to communicate and to apply as a start of a discussion. Further, it facilitates that everyone involved in the design process are given a voice. However, the pitfall of ignoring interaction is a major risk that must be addressed before and during the process.

5 Conclusion

The future MTS with autonomous vessels will be different from the present. The differences will not be merely about the autonomous vessel itself; it will also be the changes in the interaction between all actors in the MTS. This understanding calls for a holistic approach to discussing the future MTS. The VTS is a control system that contributes to a safe and efficient MTS, and consequently, the VTS is essential in the discussion of autonomy in the MTS. The VTS could take a reactive stance, perceiving autonomy being a designer challenge of making autonomous vessels that have the same capabilities as the conventional vessel. The other option is a proactive approach, where the VTS takes ownership to the overall objectives of the MTS and assess how the VTS could adapt to the future need.

The paper has suggested a proactive socio-technical systems approach to discuss a democratic process and evaluate the systemic internal and external effects of changes for the future VTS. The history of socio-technical systems theory shows a development affected by societal trends and being affected by, and merging into, other approaches.

The paper has argued the *democratic process* has several aspects, ranging from understanding users to user involvement in design. However, the focus on workers has been common denominator through history and is consequently perceived as a cornerstone of the socio-technical systems theory. The paper has proposed a democratic process involving people from the entire VTS organisation with a variety of competencies is necessary to find solutions and to warrant ownership in the design phase.

Further, the paper has argued for the systemic perspective being another cornerstone of the socio-technical systems theory. The history has shown the importance of understanding human performance in a broader perspective than the individual operator. Consequently, the paper has suggested to applying a levelled socio-technical model to understand internal consequences to potential changes. Such an approach aims to provide an insight of the consequences at the various levels, but additionally, for the interaction between the levels.

The proactive approach calls for a holistic evaluation of the future VTS. The paper suggests considering the MTS a system-of-systems and apply the system-of-systems design principles. Subsequently, the VTS as a control system needs to consider how it could contribute to positively affect the design principles of the MTS when discussing the future role of the VTS.

In sum, the paper has presented a complex challenge of taking a systems perspective of discussing the future role of the VTS. The paper has argued that a simplified socio-technical approach could support the discussion in the early design phase of the future VTS.

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Paper IV

It is not difficult, we could do it tomorrow: The Vessel Traffic Services contribution to safe coexistence between automated and conventional vessels

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It is not difficult, we could do it tomorrow: The Vessel Traffic Services contribution to safe coexistence between automated and conventional vessels

The maritime industry could face major changes the coming decade. Technology development opens for new ways of operating vessels and autonomy is argued to revolutionise design and operations. However, despite a large focus on autonomy for half a decade, no autonomous concepts have been put into operations. In our paper, we suggest an initial step towards autonomy using unmanned automated vessels. To explore this, we utilize the coherence between the systems thinking and participatory design thinking process. We frame the project to focus on the VTS traffic regulation and organisation measures in a 2025-scenario. The study shows that where standardisation of traffic would be *beneficial* for the present MTS with only conventional vessels, it will be a *prerequisite* for a future MTS with automated vessels. Further, we identify that the VTS need to change their role from solving situations ad-hoc to assume a tactical responsibility in traffic planning and to resolve situations at an earlier stage. A prototype of the future MTS shows that the identified challenges are considered possible to solve within a short time frame and is summed up in one statement from a plenary discussion: “this is not difficult, we could do it tomorrow”.

Keywords: Vessel Traffic Services (VTS), Maritime Traffic System (MTS), autonomy, automated vessels, systems thinking, participatory design

Introduction

Digitalisation opens for new technologies and for applying technologies in new ways. For all transport segments, digitalisation allows for interconnection between components, systems and infrastructure (Lambrou 2017) and could lead to new ways of operating. Autonomy is one of the new promising ways of operating made possible by digitalisation, and autonomous shipping have for some years been highlighted as the disruptive future of the maritime industry that will revolutionise both design and operation (Rolls-Royce 2016). Despite being on the top of the agenda for maritime developers for almost half a decade, no concept of autonomy has yet been put into operations. A major challenge to solve is the interaction between technology and humans in future autonomous concepts. The solution could be searched for in two directions. One is designing a safe and redundant system that do not require humans at all, the other is a design that is inclusive of humans (Lützhöft et al. 2019). While the first direction was given the main attention some years ago but with no proven success, the latter gains increasing interest.

In this paper, we focus on Norwegian waters and aim to explore if the Vessel Traffic Services (VTS) can facilitate for safe coexistence between conventional and autonomous vessels. We use a complementary mindset that includes systems thinking and participatory design thinking. Systems thinking inspires us to shift the focus from the design of the autonomous vessel alone, to focus on the Maritime Traffic System (MTS). We describe the MTS as a system-of-systems that includes conventional vessels, autonomous vessels and VTS. Further, we define the VTS as the main system of interest and apply a participatory design method to identify how the VTS could change how they regulate and organise traffic to facilitate for safe coexistence. We argue for a first step towards autonomy is to utilise digitalisation while keeping humans in the loop, and we discuss a MTS where automated vessels are introduced. The term automated vessel is used to highlight that we consider a technology development with pre-programmed and predictable vessels, however, without any intelligence to make complex decisions.

The Vessel Traffic Services, a system, a centre, and an organisation

Using the Vessel Traffic Services (VTS) as our system of interest calls for a clarification of what the VTS is. First, 'VTS' is used for describing a system that provides a service to aid the mariner in the safe and efficient use of the waterways by providing traffic regulation (passive means such as restrictions of passage or predefined routes) or traffic organisation (active interaction with vessels) (IALA 2016). Second, 'VTS centre' refers to the actual location where the service is executed from, and these centres are manned with VTS operators. Third, 'VTS organisation' is the 'Competent Authority' who is the organisation responsible for the VTS. In Norway, the Competent Authority is the Norwegian Coastal Administration (NCA) and they are responsible for five VTS centres, each manned with two VTS operators 24/7.

The interplay between VTS and MTS

The VTS is described as a sociotechnical control system in the Maritime Traffic System (MTS) (Praetorius 2014), where the MTS being a system-of-systems composed by the systems involved in navigation in an area (Relling et al. 2019). Being a *sociotechnical* system (Relling, Praetorius, and Hareide 2019), refers to the system performs through joint optimisation between social and technical factors (Mumford 2006). Further, the VTS as a *control system* points to the interaction with the environment to achieve a stable output, in this case the VTS achieving a safe and efficient traffic flow (Praetorius 2014), or, in our terminology a safe coexistence.

A recurrent objective in the autonomy discussion is creating solutions that are "as safe or safer" than today, particularly from a regulatory point of view. To consider safety, it is detrimental to focus barely on an individual system or vessel, omitting its interaction with other systems, (Relling et al. 2018). Consequently, we discuss safety in the perspective of the entire MTS. Thus, the objective of being as safe or safer should follow a systems perspective, and lead to 'safe coexistence', referring to coexistence between conventional and autonomous vessels.

The term 'safe coexistence' implies a shift of focus from the individual system in isolation, to a holistic perspective of safety achieved by the interaction between all component systems in the MTS. An apparent challenge is even though the MTS consists of observable component systems, such as vessels and the VTS, the MTS itself is not a physical system, neither a defined organisation. The MTS is a constructed term to describe an abstract system. As such, it is challenging to assign objectives or responsibilities to the system. However, the Norwegian government has given the Ministry of Transportation (MoT) the responsibility for maritime infrastructure and services for safe maritime traffic (Ministry of Transportation 2019). Consequently, we argue that the governmental objectives for a safe and efficient maritime transport is also the objective for the MTS, hence, the MoT is responsible for designing a future MTS for safe coexistence. This responsibility includes the VTS, enacted by NCA.

The system-of-systems is composed by managerially and operationally independent systems, and a consequence is that even though the VTS is a control system in the MTS, it cannot fully control the systems in the MTS (Relling, Praetorius, and Hareide 2019). The design challenge of a future VTS will be balancing the control, avoiding over-control as this will fail due to lack of authority, and under-control that will fail due to rejecting the nature of a system in the system integration (Maier 1998).

To achieve this balance, we need to understand the dynamics between the VTS and the other component systems in the MTS. These dynamics are covered by the concept of requisite variety: The VTS as the control system in the MTS, needs a variation that is equal to, or larger than, the variation of the other component systems in the MTS (Relling et al. 2019). There are chiefly two ways of such manage variety, one is to ensure a high variety in the VTS' response to situations, the other is to limit the variety amongst the other component systems in the MTS. An example of the former is how the VTS operators use their nautical and VTS-experience to interpret the situation and choose which and when services are provided. The latter could be demonstrated by how Traffic Separation Schemes (TSS) limits the variability in traffic movements (Relling et al. 2019).

In our study, we explore how the VTS could apply traffic organisation and traffic regulation to achieve the balance between VTS variety and component systems' variety. We define traffic organising as the direct communication between the VTS operator and the vessel, while traffic regulation as restrictions or rules for using fairways.

Our premises for the autonomy discussion

The maritime industry has seen an increasing use of technology, and in particular automation, the last 30 years. However, autonomy implies more and different use of technology to an extent that significantly change systems (Relling et al. 2018). In 2017, the International Maritime Organization (IMO) initiated their work to determine how Marine Autonomous Surface Ships (MASS) could be introduced in IMO instruments (IMO 2020). The acknowledgement by IMO is an important signal that autonomy is of high priority for many of the member states. It is believed that autonomy would imply substantial consequences for the navigation and operation of future ships (Praetorius, Hult, and Sandberg 2019). However, to provide an accurate definition of autonomy is a challenge (Relling et al. 2018), and a part of this challenge is how autonomy relates to, or is the same as, unmanned ships or smart ships (Praetorius, Hult, and Sandberg 2019). In our perspective, the autonomy discussions and further development are challenged by the expectations for autonomy are higher than the actual capabilities. Consequently, we have defined the use premises for the study that consider both technical and human capabilities:

- We consider the vessel's capability to be limited to follow pre-programmed routes with only a minimum of abilities to take additional action

- We discuss vessels where there are no humans on board to execute the navigation function.

- The vessel is supported by a shore centre. However, we should consider known human limitations and challenges for the shore operators related to factors such as fatigue, ship sense, perception and attention, situation awareness, mental models (Porathe, Prison, and Man 2014)

Objective

In this paper, we focus on an initial step in maritime autonomy where we consider automated vessels. Further, we consider a holistic perspective, and how the VTS could contribute to the MTS objectives of safe coexistence between its component systems. We explore how the VTS can balance the level of control where traffic regulation and organisation are applied to balance the variety of the VTS variety and the other MTS component systems' variety. The research question for the paper is:

Can a future Vessel Traffic Services facilitate for safe coexistence between conventional and automated vessels by traffic organisation and traffic regulation measures?

Materials and methods

In our study, we use a complementary mindset between systems and participatory design. The link between the two mindsets is found in their common aim to find solutions of complex problems, and to understand critical variables and functionalities (Lewrick, Link, and Leifer 2018). If the overall picture is unclear Lewrick et al. (2018) suggest moving from design thinking to systems thinking, and if a personal stamp pervades the systems thinking, the design thinking process is suggested to expand the creative framework. We refer to Lewrick et al.'s model of overlap between systems thinking and design thinking as visualised in Figure 1 where we have highlighted the process steps used in this study. In general, we could say that we use systems thinking as the background for the study and participatory design thinking to suggest solutions within this given frame.

The background section in the paper describes our stance of focusing on automated vessels, the interplay between VTS and MTS objectives and the limitation of assessment of how the VTS' role to balance control through traffic organisation and regulation. As such, the background section is a systems thinking approach and summarises the three initial steps in Figure 1 of situation analysis, finding & defining goals, and develop situation variants. Participatory design thinking is used for ideating and developing & testing prototypes.

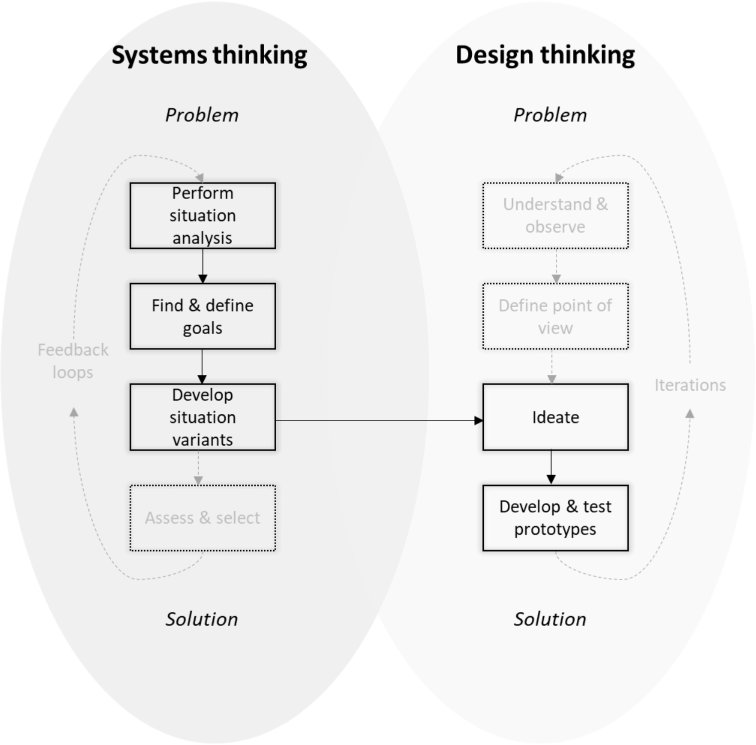

Figure 1: The processes in systems thinking and design thinking have many similarities and Lewrick et al. (2018) suggest combining these mindsets. The highlighted process steps are used in this study. The three systems thinking process steps are used to present the framing of the study, while the two design thinking process steps refer to the process for data collection and analysis.

The paper follows the flow in Figure 1. The introduction chapter presents our stance related to situation analysis, goals, and situation variants. The situation analysis describes our stance to include humans in the digitalisation of the maritime industry. The goals are reflected in the interplay between the VTS and the MTS, while the situation variants are framed by the premises for the study. Further, the results chapter presents the ideation phase and the development and testing of prototypes. The ideation phase is described in the sub-section implications for safe coexistence in the MTS, while the prototype is assigned a separate sub-chapter.

For ideation and developing and testing of prototypes we apply focus groups. Focus groups are useful for wide range of features, such as the use of subject matter experts to discuss design, prototypes or operational systems (Stanton et al. 2013). In our study, the use of focus groups with personnel with thorough and various knowledge of the VTS, was expected to provide valuable insight to how to find a good balance of control level in the future MTS.

Sampling

The selection of participants was planned in cooperation with NCA. In a preparation meeting, we presented the objective of the study to the five VTS managers and requested participation from the managers and in addition minimum one representative from each

VTS. The VTS managers suggested to participate together with one VTS instructor per VTS centre. If shift rotation made instructors unavailable, they would assign an experienced VTS operator to participate.

Since the managers decided who would participate and the sampling is considered purposive and non-probabilistic. The first workshop had 14 participants, while the second had 12 participants. All Norwegian VTS were represented on both workshops. All VTS managers, VTS instructors and VTS operators have nautical background as a navigator.

Table 1: Workshop 1 had 14 participants and workshop 2 had 12 participants

	VTS managers	VTS Instructors	VTS operators	NCA management	Total
Workshop 1	5	4	2	3	14
Workshop 2	4	3	2	3	12

Procedure

The data collection was conducted in November and December 2019. The objectives for the study were presented in a preparation meeting with all VTS managers were facilitated by NCA September 16th 2019. A written presentation of the project was sent out via e-mail after the meeting. The managers were invited to provide input both during the meeting and in the e-mail. In the preparation meeting, the dates for the workshops was set, and the study was added as a work package in an on-going NCA project on ‘the future VTS’.

Workshop 1 was held in Ålesund November 21-22nd 2019 where the research project was allotted a 3-hour time slot. The time slot was divided in three main parts; an introduction to present and frame the project, focus groups to discuss the future VTS and a plenary discussion.

The research project was introduced by a brief presentation of the on-going technology development and autonomy discussion. Subsequently, the project’s premises of human and technical capabilities and limitations were presented. To further frame the discussion, a 2025-scenario with an automated container vessel intended to sail between Ålesund (NO AES) and Sykkylven (NO SYK) (marked with red circles in Figure 2) was presented. The area for the scenario is one of NCA’s test areas for autonomy.

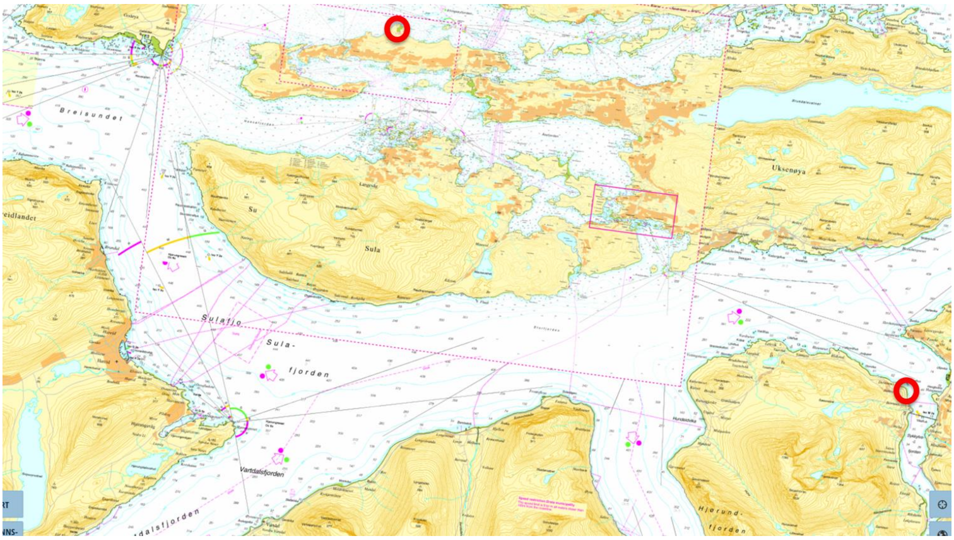

Figure 2: The geographical area for the scenario. The automated vessel will sail between the ports marked with a red circle

In the final part of the introduction, examples of potential existing and new traffic regulation and organisation measures were presented. The participants were split in two focus-groups, and instructed to discuss the future VTS based on the following questions:

1. What would be the challenge for today's VTS in a future MTS?
2. How could regulation and organisation measures be applied to facilitate for an automated container vessel between Ålesund and Sykkylven?

Workshop 2 was held in Stavanger December 12-13th 2019 where the research project was allotted a 2-hour time slot. Initially, the results from workshop 1 was presented to all participants as a prototype of the 2025 MTS. The participants were asked the following questions:

1. Does the prototype reflect your statements from the first workshop?
2. What situations would be most challenging in the scenario?

The first question was discussed in a plenary session, while the second question was answered in three focus groups.

Analysis

All focus group discussions and plenary discussions have been recorded and transcribed. When reviewing the data from workshop 1 it became clear that question 1 and 2 overlapped, and it was decided to merge for the coding process. The data was coded using Nvivo analysis software. The data was deductively coded to four nodes: VTS Traffic regulation, VTS traffic organisation, Automated vessel and shore centre, and conventional vessel. The nodes were further inductively coded. To allow for a better overview of all data, the text was translated to English language, concentrated to shorter text, and grouped.

The results from the analysis have been used for two outputs. Initially, we present the results per node. Subsequently, we present a prototype for a 2025 MTS.

Reliability and validity

In our study, we need to consider how values might affect the reliability of the study. The role of the researcher will inevitable affect any project. We argue for being considerate of this through being open with the identified challenges and choices made in the process.

The main challenge has been to frame the project and at the same time avoid an improper influence on the discussion between the participants. The main researcher has a background from air traffic management and uses this background to explore similarities and differences between aviation and the maritime industry. Our concern has been to find the balance of how many concepts and ideas from aviation should be presented to the participants. On one hand, an excessive use of own ideas and reflection could easily make the workshop about confirming own ideas, and consequently have a low reliability. On the other hand, the workshops where representatives from all the VTS' are present, is a unique opportunity to gather data for this topic, and a too wide discussion might not provide any input to our research. In preparing our data collection, we discussed the approach internally in the project and externally to fellow researchers not involved in the project. We argue we ensure reliability by:

1. The participants are experienced personnel who we expect can evaluate our suggestions rather than confirming them.
2. We presented clearly what was our stance, what were our suggestions, and that we expected the participants to use our suggestions as inspiration of discussion, not as solutions.
3. To avoid affecting the discussion, we instructed the focus groups to facilitate the discussion themselves. The questions were handed out in written format and one researcher visited the groups several times during the focus group discussions to answer any occurring questions.
4. After the data collection, we revisited our suggestions, to see how many of them that ended up as solutions. Even though some of them was used as inspiration, many of the suggestions were not taken further. In our perspective, this indicates an open discussion in the focus groups rather than confirming ideas.

The possibility to gather the same participants for two workshops made it possible to increase internal validity and credibility. Credibility is to create isomorphism between the participants perspective and our reconstruction (Fishman 1999). The presentation of results through an imaginary voyage was useful and opened for clarification and corrections. A different source for credibility is the linkage to theory (Wilson and Sharples 2015). The combination between systems thinking and participatory design thinking has linked the input from participants to sociotechnical systems theory which has a strong foundation in social science.

A weakness of the study linked to both external and internal validity. The study has only gathered data from one group of participants. Even though participation from all VTS' and on various levels in the organisation, increase internal validity by increased transferability, the study could be strengthened by increasing the sample size and validate findings against other component systems in the MTS.

Finally, the premises for the study, considering an automated vessel and human limitations in defining the shore control role, frames the discussion and could to a certain degree limit the generalisability to a broader autonomy discussion.

Results

The results from the study are presented under the topics traffic regulation, traffic organisation, automated vessel and shore centre, and conventional vessel systems. Further the results are used to prototype a 2025 MTS with an automated vessel.

Implications for safe coexistence in the MTS

The output from the ideation phase is presented in the following. We use the term 'VTS' to refer to the participants meanings, this is because the focus groups are composed of people from the entire VTS organisation. Even though an automated vessel was presented as the concept of autonomy in the study, the discussion shifted between autonomy as a general term, and the automated vessel more specific. In the results we use autonomy to reflect where the discussion was on a general level, and automated vessel when it was specific to our concept.

Traffic regulation

The VTS considers standardisation of conventional traffic as a *prerequisite* for autonomy to become a reality. However, regardless of the autonomy discussion, a standardisation of the traffic is seen as beneficial to increase predictability and consequently safety. After the introduction of the Electronic Chart Display and Information System (ECDIS), the VTS has experienced a shift in the traffic pattern. They more frequently experience vessels not following the normal route in the fairway and taking short-cuts. The reason is believed to be that ECDIS have given navigators confidence to follow a route that reduce sailing time and cost. This development leads to a high variation in the maritime traffic picture and is by the VTS seen as an increasing challenge. One solution to counter this challenge is standardisation of traffic. Such standardisation could follow different paths, and the VTS especially highlights the use of *standardised routes* and the use of *Traffic Separation Schemes (TSS)*. The VTS believes that both standardised routes and TSS should be used by conventional vessels only, also after implementation of automated vessels. However, both measures are important for separating conventional traffic from automated vessels, and to increase predictability and to detect deviations early.

NCA is in progress of defining standard routes, and these are made available for navigation planning. The VTS emphasises that this work needs to be continued and the routes must be named with names that are easy to understand to avoid misunderstandings. At present, navigators use geographical names to explain their routing, and, in particular for foreign navigators, this could easily lead to misunderstandings. The VTS suggests that the pilot boarding marks should be evaluated in parallel with this initiative to avoid pilot boarding operations in the hot-spots where standard routes with high traffic cross each other. Traffic Separation Schemes (TSS) are considered by the VTS to be one of the most important safety measures for regulating traffic, and when combined with VTS, the TSS leads to a high effect on safety. In Norway, the VTS has positive experiences with the use of TSS and this could be used more and in connection with roundabouts to reduce conflicts where traffic lanes cross each other.

For autonomous operations, the VTS suggests that it must be limited to predefined '*autonomous routes'* for exclusive use of the automated vessels. These routes must be approved, given a unique identity, and published by the NCA. The purpose is to make the routes known to all navigators in the area and could be compared to how ferry crossings are marked in nautical charts. These autonomous routes are suggested to be located in the centre of the fairway, and when used in connection with a TSS, the autonomous route should be placed in the centre of the TSS (in the separation zone).

The VTS foresees an application process where the responsible for an automated concept applies for using a specific route between defined ports. NCA should evaluate the concept and be responsible for an approval. The automated vessel is then only allowed to use the approved route and call at approved ports, and no other routes or ports could be used without an additional approval.

Even though the VTS is positive to the possibility to regulate the traffic to separate automated from conventional traffic, some challenges are identified. First, the VTS raises the challenge of how to regulate the traffic in narrow waters. In open waters, as in the scenario discussed, it is enough space for establishing TSS, standard routes, autonomous routes, in-shore traffic zones, and in addition space for unregulated sea space. In narrow waters, this might not be possible, and an unanswered question is if this indicates that autonomy is only possible in open waters. A different challenge is how to formalise a regulation such as an autonomous route. The VTS suggests that the international regulation for preventing collisions (COLREG) needs to be updated with a new section for autonomous operation. They see the development of national regulation as a minor challenge, but to develop international regulation through IMO is perceived as a protracted process.

Traffic organisation

The VTS believes introducing automated vessel in the MTS will lead to significant changes to the VTS role. At present the VTS mainly solves situations ad-hoc, and the VTS believes that this must change to the VTS takes a tactical responsibility in traffic planning and resolving potential conflict situations at an earlier stage than today. Further, the role of the VTS is considered to be of high importance when automated and conventional vessels coexist, and the VTS states that automated vessels should only operate within a VTS-area.

The use of *time slots* is one step to allow the VTS to take a different role. Time slots are used to give vessels a time frame for their departure. The VTS states that they should be responsible for assigning these time slots, and such solution should be implemented regardless of autonomous operations. The use of time slots would provide added value for coordinating other services as e.g. pilots, tugboats, and port services. Time slots is not new to maritime industry, it is already used in some major ports, and the VTS believes that it would be a minor challenge to implement in Norwegian ports.

Clearances for departure are already used by the VTS; however, they state that it is necessary to use it more and in a stricter way. At present, some vessels ask for clearance a long time before they actual depart. Other vessels never ask for clearance and just depart. The VTS thinks that the request for departure time and routing chiefly should be sent via the reporting portal SafeSeaNet. When ready for departure, the actual clearance should be requested by the vessel, and given by the VTS, on voice communication. Departure should be commenced immediately after clearance is given. The VTS see no major differences between automated and conventional vessels for requesting routing and clearances. The only difference they see is that for conventional vessels the task will be done by the navigators, while a shore centre will be responsible for checking that operational conditions is acceptable, and subsequently, forward the request for the automated vessel. For traffic organising, the main difference between the two types of vessel is that for automated traffic, the autonomous route will be activated, while conventional vessels will primarily follow standard routes that are continuously active.

For the VTS this implies that if the autonomous route is unavailable by some reason (rescue operation, vessels in the route not responding on radio etc.), the VTS has to retain the clearance. Conventional vessels will not face the same restrictions as they are more flexible to interpret the situation and deviate from their planned route. The VTS discussed if the clearance to automated vessels should be graded green, yellow or red. Green would tell the shore centre that low traffic density is expected, while yellow indicates medium, and red heavy traffic density. Such clearance grading could assist both VTS and the shore control centre to be more aware of situations in dense traffic areas. However, the discussion unveiled challenges of graded clearances, such as traffic situations change during the voyage and problems with deciding on criteria for the various grades of clearances, and the discussion remained un-concluded.

Condition-based clearances is used to some extent by the VTS today. When large tankers are entering or leaving oil refineries, the VTS in some situations restricts other vessel movements in the area. In such cases, they use a condition-based clearance where the clearance is valid when a condition is fulfilled. For example, a small vessel could be cleared to cross an area aft of the tanker vessel. Such clearances are used regardless of the small vessel has the right of being the stand-on vessel in accordance to COLREG. The VTS does not see this as violating COLREG as long as the condition-based clearance is provided so early that the conflict situation is avoided by minor course or speed changes.

The use of *clearance for routing* is another important measure to organise traffic for the VTS. Clearances combined with routes (standard routes/TSS for conventional vessels and autonomous routes for automated vessels) are expected to give the VTS adequate predictability to separate conventional from automated vessels. In general, the VTS thinks that the automated vessel should maintain speed and always remain inside the autonomous route. As such, most of traffic organisation will be imposed on the conventional vessels. However, the VTS highlights that they need to be able to stop or change clearance for the automated vessel as well. In this case, they need to contact the shore centre, which executes the VTS order. A difference between automated and conventional vessels is that conventional vessels primarily deviate course rather altering speed to avoid conflict situations. Automated vessels operating on an autonomous route should not be allowed to exit this route, and to avoid a conflict situation, speed is the only variable. The VTS believes that the automated vessel should have the capability to come to full stop and hold position if an abnormal situation occurs. This infers some kind of dynamic positioning capability for the automated vessel.

The VTS opens for *automated solutions for organising* some types of traffic. For traffic frequently trafficking an area, an automated traffic organising system could calculate the best flow of traffic. As an example, when the automated vessel approaches a ferry crossing, the system could calculate how the automated vessel and the ferries could adjust their voyage to avoid conflicts. The VTS role could be to monitor that calculation has been performed and all vessels have accepted the calculated solution.

The VTS raises the question of how to separate the automated vessel from smaller vessels not under VTS control. Even if the automated vessel operates in the centre of the fairway in pre-defined routes, some might not be aware of the limitations of the automated vessel. In particular, leisure boats could have little knowledge of routing and the capabilities of other vessels. The VTS suggests that the automated vessel should have conspicuity paint, so it is easily seen. The VTS discusses if a unique navigation light signals for automated vessels should be defined. However, as this might contradict to international rules, this was discussed to create more confusion than clarity. The technology development leads to vessels have access to increasingly more information.

Either through on-board equipment or using smart phones, a special AIS-tag on the automated vessel and highlighting the autonomous route could be helpful for both leisure boats and commercial vessels. Regardless of introducing technical safety measures, the conflict situation between small leisure boats is a situation that is not possible to control by the VTS. They expect that the automated vessels have some sensors that could detect approaching vessels, and consequently could reduce speed or stop. However, a different challenge is if creating an expectation of the automated vessels always will stop, this could also create dangerous situations. Either by someone that finds excitement by purposely pass close to the vessel to provoke the automated vessel to take action, or by someone that ignores the automated vessel since they know it will stop or reduce speed anyway. Further, it was said that large commercial vessels not deviate for small leisure boats anyway, and the leisure boats will not experience a difference between an automated vessel and a commercial vessel.

The VTS discusses both organisational and technical aspects important to traffic organisation. The scenario under discussion with an automated vessel will affect the workload for the VTS, and they foresee that such operation would probably cause that an additional operator would cover the area of the automated operations. However, the VTS believes that this is an imperceptible cost compared to the benefits of reduced crew cost. Technical solutions are also considered important to cope with a new role of organising this type of traffic. First, the importance of sufficient radio and radar coverage in the area of automated operations is highlighted. Good radar coverage allows for defining better alarm criteria that warns the VTS operator of vessels deviating from their intended course and about vessels inside the automated route. Second, the VTS emphasises that the functionality of their equipment should assist the VTS operators. Information should seamlessly be passed between vessels and shore centre and the VTS. Further, technical solutions should be used for decision support for the VTS operator.

The automated vessel and shore centre

The VTS expresses expectations to the capabilities of the automated vessel. The automated vessel is expected to be able to accurately follow a route at a given speed, and to have redundant safety critical equipment. If more than one automated vessel operates in one area, the accuracy should allow for automated vessels pass each other on opposite directions within the same autonomous route. In addition to the previously mentioned dynamic positioning capability, the VTS expects the shore control to be able to do some basic manoeuvring. The manoeuvrability demonstrated on trial runs that the VTS has observed so far, is considered as insufficient, and they expect this to be improved. The VTS raises the question if the automated vessel should be categorised permanently as ‘limited ability to manoeuvre’. On one hand, the VTS sees it as problematic that with this categorisation the automated vessel will have priority over all other traffic. On the other hand, the use of limited ability to manoeuvre is quite common world-wide, and such rules will probably be normalised in our area quite soon.

The VTS says if a problem with the automated vessel occurs the shore centre should stop the vessel, and then upload a new route that needs approval and clearance from the VTS to initiate. However, it could be situations where adjustment of, primarily, speed, but also potentially course, are needed. They discussed if the VTS should be given the possibility to ‘push the stop button’. One argument for allowing this was that this is comparable to instruct a vessel to stop. This argument was countered by an instruction is given to a navigator who executes. Transferred to an automated vessel, the instruction is given to the shore centre, and they execute. Hence, the shore centre should always be responsible for execution of orders to the automated vessel.

Conventional vessels

The main implications for conventional vessels are described by more and stricter traffic regulation and organisation. The VTS describes the consequences for the conventional vessels might be less flexibility. On the other hand, they emphasise that increased predictability would be positive for the conventional vessels and refers to experience with introducing TSS. Further, the autonomous route must be shown on ECDIS to reduce misunderstandings. The VTS suggests that conventional vessels could set-up alarms to be triggered if they enter autonomous routes. However, to impose such requirements on international vessels is difficult.

A prototype of a future Maritime Traffic System with an automated vessel

The final step in our approach is to develop and test a prototype. The identified results have been used to design a prototype of a MTS in 2025. The scenario used to test the prototype is a voyage of an automated vessel between a container terminal in Aalesund to an industry area in Sykkylven.

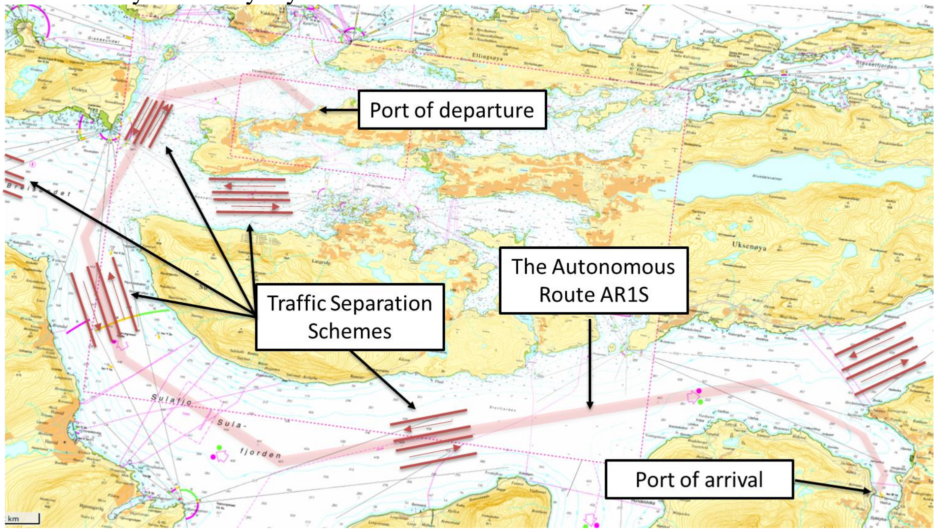

Figure 3: The prototype of the MTS with an automated operation in the autonomous route AR1S and Traffic Separation Schemes

Time	Situation	Reasoning
09:00	The container terminal notifies the shore centre (SC) that the containers will be loaded on-board at 11.00.	The SC is responsible for planning and coordination the

09:10	SC checks weather forecast and loading conditions, and contacts port of arrival to ask when they are ready to receive the containers. Due to the quay is occupied, the arrival port request arrival of the vessel to be at 15.00.	operation in accordance with the operational .criteria. SC will request route and departure time via SafeSeaNet. Some communication between VTS and SC could be electronically.
09.15	SC programs departure from NO AES at 11.00 and arrival at NO SYK at 15.00 and choose route 'Autonomous Route 1 South' (AR1S) for the voyage. Based on weather and current the SC calculates a transit speed of 6 knots.	
09.20	SC transfer the requested route, speed, and departure via SafeSeaNet (SSN).	
09.20	VTS receives "request for departure" from SC. The request is routed from SSN directly into the VTS Operator Support Station (OSS) The OSS informs that the departure conflicts with another departure and presents the first available time slot to be 11.20. The VTS operator assigns the 11.20-time slot to the automated vessel and this triggers a "preliminary schedule for departure" to SC.	VTS should be responsible for time slots. VTS approves routing, speed, and departure. VTS should be supported by technical solutions.
09.25	SC receives "preliminary schedule" and speed is automatically updated to 7 knots to meet requested arrival time at 15.00.	

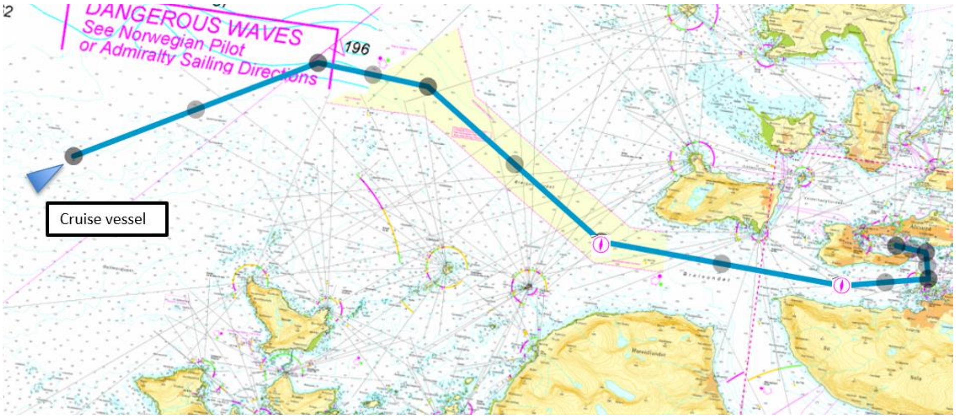

Figure 4: A cruise vessel reports to enter the area, and receives a condition-based clearance from the VTS

Time	Situation	Reasoning

10.30	A cruise vessel checks in on the VTS frequency and report 30 minutes until entering VTS area and requests clearance for entry in accordance planned route AES E1 at time 11.00 VTS checks the OSS and confirms that the cruise vessel is on schedule for the assigned time slot for entry. The OSS warns that with current speed at 15 knots, the cruise vessel will conflict with the automated vessel. VTS gives the cruise vessel clearance to entry AES E1 at maximum speed 13 knots and informs about traffic is automated vessel at AR1S. Cruise vessel is cleared to proceed and cross aft of the automated vessel. The VTS enters speed 13 knots and checks that time for pilot boarding is changed by 12 minutes. The SSN automatically informs the pilot distribution centre. The cruise vessel reads back entry clearance.	Standard routes should be used by conventional vessels. Pilot boarding should be moved away from hot spot areas. VTS will organise traffic by condition-based clearances. The VTS should take a role of organising the traffic by planning. If done in proper time COLREG situations will not occur. OSS and SSN should support the VTS operator.
11.00	VTS receives a phone call from the local sail club who informs about a planned training in the area. The VTS informs about AR1S is active, and this implies that if the sail boats cross the route, they are give-way vessels.	Automated traffic regulation will affect and potentially could reduce flexibility for other traffic.
11.10	SC notifies the container terminal that departure is scheduled in 10 minutes. SC scans the area with their sensors.	The automated vessels will have sensors to monitor the situation around the vessel. SC is responsible for initiating departure.
11.10	VTS OSS informs VTS operator of 10 minutes for departure of automated vessel and the VTS operator scans the AR1S for traffic.	VTS needs sufficient radar coverage for the entire area.
11.20	VTS activate AR1S and transmits the clearance for departure on AR1S speed 9 knots on the radio frequency.	VTS is responsible for clearances.
11.20	SC initiate departure procedure and confirms with camera that all navigation lights works, and checks AIS-signal is on.	The automated vessel must be easy to recognise.

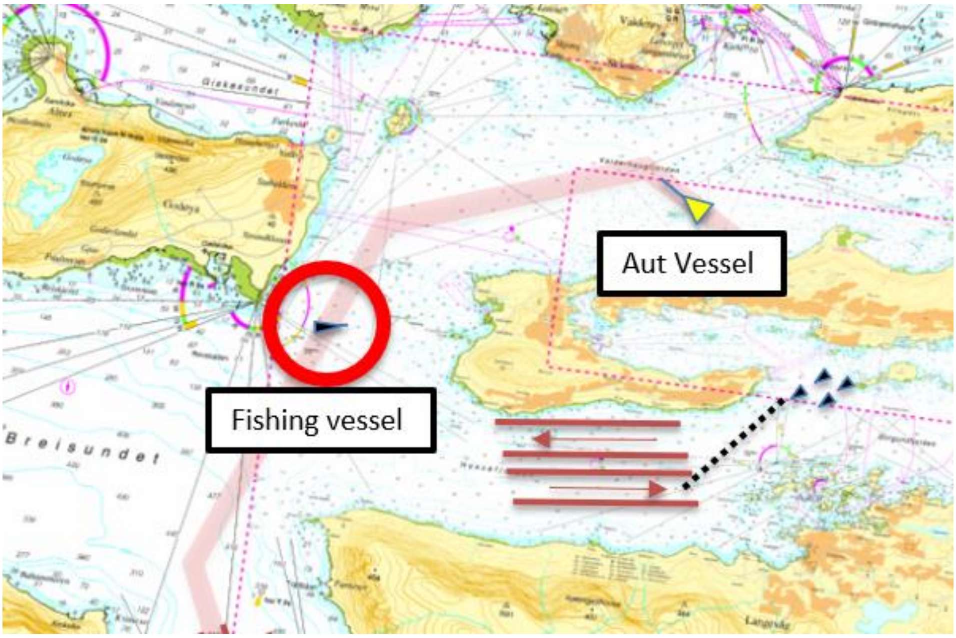

Figure 5: A fishing vessel starts fishing in the AR1S. The VTS is warned by an alarm.

Time	Situation	Reasoning
11.30	An alarm is triggered at the VTS. The radar has detected a track inside AR1S. The VTS operator sees that the track has no AIS signal and no one is responding on the VTS work channel on radio. The VTS operator calls the vessel on the distress channel (channel 16). A fishing vessel responds and acknowledge the VTS instructions of setting course east immediately.	VTS needs sufficient radar and radio coverage for the entire area. Standardised routes allow for precise alarm criteri.a
11.40	The cruise vessel confirms AIS contact with the automated vessel.	The automated vessel should be easily recognised by a special AIS-designator.

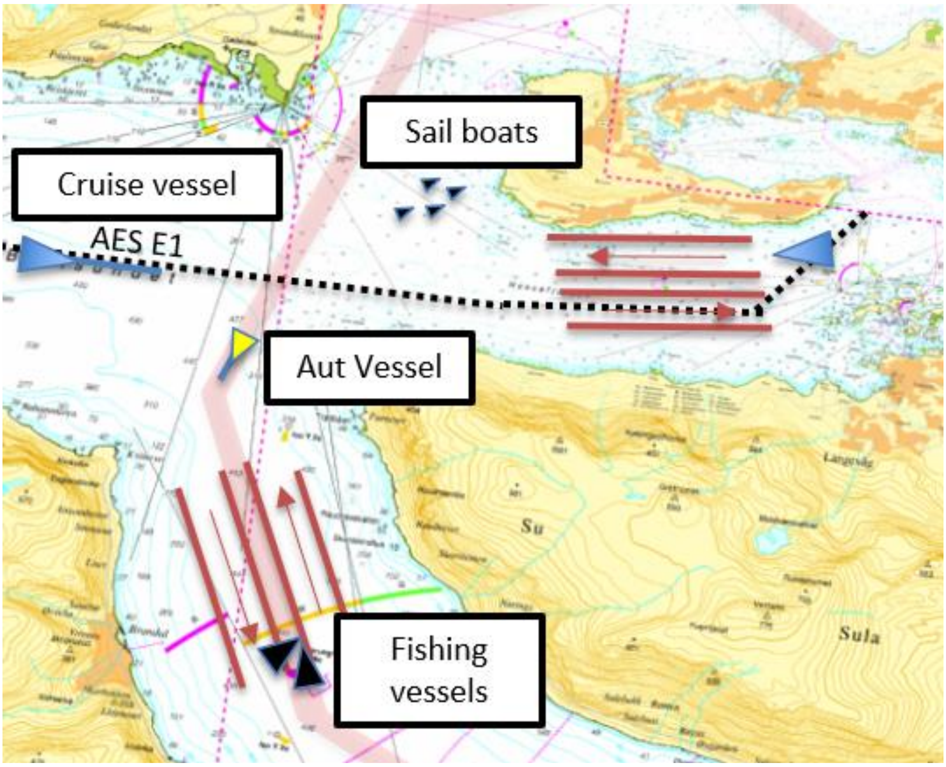

Figure 6: If a situation occurs in the autonomous route, the automated will reduce speed and never leave the autonomous route

Time	**Situation**	**Reasoning**
12:10	A fishing vessel with engine failure gets an alarm on the ECDIS of drifting inside an active autonomous route An alarm is triggered at the VTS. The radar has detected a track inside AR1S. VTS receives a radio call from the fishing vessel saying they have assistance from another fishing vessel that will start towing as soon as the towing line is secured. The fishing vessel asks if the automated vessel could pass west of them. VTS responds that course deviation outside AR1S is not possible, but the automated vessel will reduce speed or stop. VTS calls SC and instructs the automated vessel to reduce speed to 5 knots. The SC executes the speed reduction	Conventional vessels could be warned if they are inside an active autonomous route. The automated vessel will mainly adjust speed, and will not leave the autonomous route. The SC is responsible to execute instructions from the VTS.

	The fishing vessel reports that towing is initiated and that they are clear of AR1S VTS calls SC and informs that the automated vessel could proceed as planned. SC increases speed of the automated vessel.	

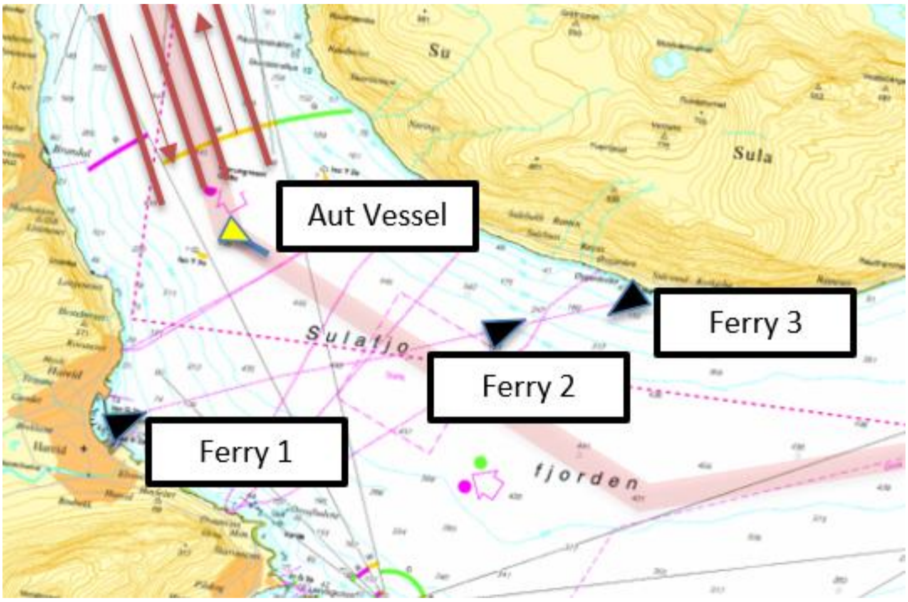

Figure 7: An automated solution to resolve situations between the automated vessel and vessels that frequently trafficking the area is suggested

Time	Situation	Reasoning
12:50	The automated vessel approaches a busy ferry crossing area. The automated traffic organisation system has suggested that Ferry 1 deviate 10 degrees port and Ferry 3 increase speed by 2 knots and cross in front of the automated vessel. When the navigators of Ferry 1 and 3 have accepted the VTS is informed by a green signal on their work station. The extra fuel consumption is logged by the ferries and reported to their shipping company.	An automated technical solution to resolve situations between the automated vessel and vessels that frequently trafficking the area is suggested.

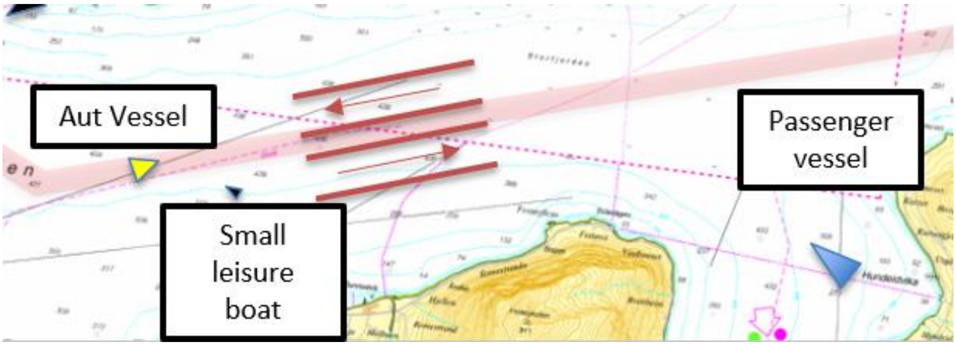

Figure 8: The automated vessel might experience conflict situation with vessels under VTS control and vessels not controlled by the VTS

Time	Situation	Reasoning
13:15	A passenger vessel is outbound and is notified by the VTS about the automated vessel. The passenger vessel reports AIS and radar contact and they will cross AR1S and enter TSS westbound and confirms they will maintain separation from the automated vessel.	VTS needs sufficient radar and radio coverage for the entire area. The automated vessel should be easily recognised by a special AIS-designator.
13:20	The VTS and SC are warned about a small high-speed leisure boat is on collision course with the automated vessel. The automated vessel is categorised as 'limited ability to manoeuvre' and even though the leisure boat approaches on the starboard side, the autonomous vessel is the stand-on vessel and maintains speed and course. After an unsuccessful call on all radio channels, the VTS calls the SC. SC informs that the automated vessel has automatically initiated sound and light warning. The VTS observes that the small leisure boat crosses in front of the automated vessel, but inside the published safety zone for the automated vessel. SC downloads video recording from the automated vessel and confirms that they will create a non-conformance report.	VTS needs sufficient radar and radio coverag.e for the entire area The automated vessel could be categorised as limited ability to manoeuvre. The automated vessel should have some pre-programmed solutions for difficult situations. Alarm criteria could be well defined based on predefined routes.

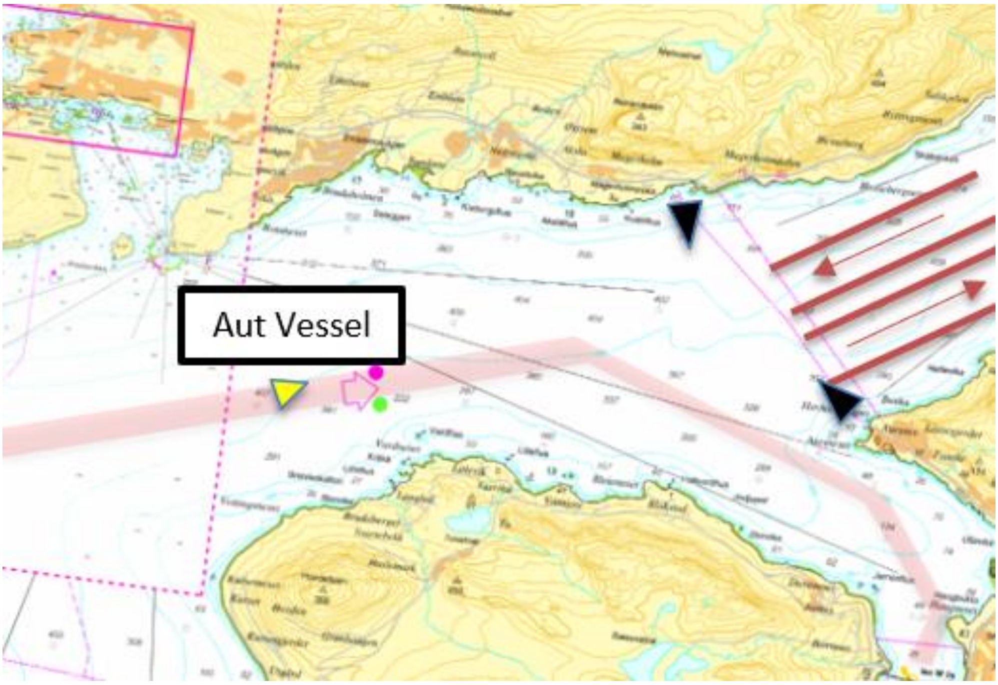

Figure 9: In case of a black-out, the automated vessel should have a back-up solution that keeps the vessel inside the autonomous route

Time	Situation	Reasoning
14:30	The automated vessel has a black-out. The SC is warned immediately, and the VTS is warned 2 minutes later. The automated vessel uses emergency power to stop the vessel and use a back-up dynamic positioning system to remain inside the AR1S. VTS scans the area and informs the ferries east of the automated vessel. The ferries could confirm the VTS' radar picture; the automated vessels lay still in the middle of the AR1S. SC initiates procedure for black-out and orders tug	VTS needs sufficient radar and radio coverage for the entire area The automated vessel should have some pre-programmed solutions for difficult situations The SC is responsible for the operation of the automated vessel
15:00	SC manages to restore contact with the automated vessel. SC sends a request to recommit voyage to the VTS	SC will coordinate and plan the voyage SC will request route and departure time via SafeSeaNet

	The VTS issue clearance to continue voyage. SC sends order to continue of voyage to the automated vessel. Speed is increased to 11 knots due to delay.	Some communication between VTS and SC could be electronically.
15:20	The automated vessel arrives port .	

Discussion

The results show that the participants have ideated a wide range of measures to facilitate for safe coexistence of automated and conventional vessels.

To regulate traffic, standardisation of both conventional and automated vessels movements is important. The use of standardised routes and TSS are both measures that already exist, and an interesting aspect is that the VTS thinks it is necessary to standardise traffic movements regardless of autonomy. When introducing automated traffic, standardisation is considered as a prerequisite and the VTS suggests using specific autonomous routes. The suggested traffic regulation measures are expected to increase predictability for all involved systems in the MTS. The predictability is caused by being easier to know the intention of all vessel types. However, it is important to notice that the VTS warns against less flexibility for the involved vessels. Both number of routes being implemented and how they are introduced, could be linked to the balance of control in a system-of-systems. On one hand, if routes are defined without user involvement and made mandatory for conventional vessels, we could face the risk of over-controlling and might fail due to lack of authority. On the other hand, if several routes are published without incentives to follow them, a situation of under-control could be experienced. We believe that a step to find the balance is to apply the complementary system and design thinking process to users from all systems in the MTS.

The most prominent result in traffic organisation in a future MTS, is the VTS' belief of taking a new and different role. They state that they need to shift from solving situations ad-hoc to take a tactical responsibility in planning and resolving conflict situations earlier than today. As for regulation of traffic, this role change could be a necessity regardless of autonomy. Digitalisation enables more information to be shared between vessels and between shore and vessels. Information exchange could partly replace the role of the VTS. A better AIS-coverage with more available information and implementation of Sea Traffic Management services to exchange intentions are only two technological developments that could make some of the services provided by the VTS obsolete. The use of time slots and clearances are measures that could be labelled as low-hanging fruits for the VTS to shift their role to take tactical responsibility. The availability and possibility to integrate information such as port availability and services such as pilots, tugs, or port services, could legitimate the responsibility for assigning time slots to the VTS. In combination with a stricter use of the clearances, the VTS could increase their time horizon, hence, increase the possibility to take a tactical responsibility. The shift in responsibility also opens the door to control the variety in the MTS. When the VTS is responsible for assigning time slots and issuing clearances they reduce the variety of the other component systems in the MTS.

The results indicate that it is important to further develop technology to support decision makers in the MTS. The VTS suggest making use of integrated information via SafeSeaNet and by use of their Operator Support Station. They suggest that standardising traffic allow for better alarm settings both on the VTS and on the vessels. Further, they believe that technology could relief the VTS responsibility, by calculating meeting points and suggesting resolution for conflicting traffic between vessels frequently trafficking in the same area as the automated vessel. The VTS also expresses some expectations to the automated vessel, such as high reliability that ensure the vessel to keep its route and speed and have sufficient back-up options. Additionally, by having a unique AIS-tag and conspicuity paint it should be easier to discover for vessels both under VTS control and outside VTS-control.

The prototype of a future MTS where the automated vessel has a problematic voyage with several conflict situations, shows that the challenges mentioned by the participants could be combined with identified solutions. On one hand, this is natural since it is the same participants identifying problems and suggesting solutions. On the other hand, no conflict situation was left without any solution at all. To strengthen the results, the prototype could undergo additional interactions with different users to identify more conflict situations, and potentially more and better solutions.

The study argues for the importance of lifting the 'as safe, or safer' perspective from the individual vessel to the interaction between systems in a safe coexistence. We argue that the prototype is a good example of how this is done in practical terms. Rather than identifying solutions for how the automated vessel should adhere to existing regulations, we see a prototype sharing the responsibility of separation between all system components: The automated vessel is responsible to maintain a predefined route at a given speed, the shore centre is responsible for planning, initiating the voyage, and stop the vessel if instructed by the VTS, the VTS is responsible for tactical planning to avoid conflict situations, and conventional vessels is responsible to follow predefined routes and adhere to VTS clearances.

A question that remains partly unanswered is what if a conflict situation occurs despite the abovementioned responsibilities? In the prototype we saw a leisure boat approaching the autonomous vessel. The solution of categorising the automated vessel as limited ability to manoeuvre will in most cases lead to other vessels being give-way vessel. As the participants point out, such solution is not straight-forward, since this permanently gives the automated vessel priority and might be experienced as an unjust solution to other vessels and potentially create dangerous situations. In future research, this problem should be explored further.

In sum, the measures and technologies suggested by the VTS are partly related to autonomy. However, many of the discussions were related to a shift in the MTS that calls for a change of the VTS role, regardless of autonomy. One interesting finding is that the measures that is related to bringing an automated vessel into the MTS, are no futuristic measures. A statement that summarise this was given after a plenary discussion of the scenario and measures; *"this is not difficult; we could do this tomorrow*". The statement should not be interpreted as everything being in place right now, but the participants did not see any large barriers or showstoppers for introducing the measures within relatively short time.

Conclusion

In the study, we have explored if the future Vessel Traffic Services (VTS) can facilitate for safe coexistence between automated and conventional vessels. We have discussed an initial step of autonomy; an unmanned automated vessel with support from a shore centre that operates in a 2025-scenario in one of the test areas of autonomy on the west coast of Norway. We have applied a complementary mind-set between systems and participatory design thinking. The systems thinking provided the background and the frame for the participants design thinking process and was used to lift the autonomy discussion from the automated vessel alone to discuss interaction for all component systems in the Maritime Traffic System (MTS). Further, we argued that since the VTS is a control system in the MTS, it is important to consider the MTS objectives when designing the future VTS. By considering the MTS as a system-of-systems, we claim that balancing the control to avoid over- and under-control in the MTS is imperative, and the role of the VTS will be central in this balance

The participants from the VTS identified traffic regulation measures that standardise traffic and increase predictability. Extended use of standardised routes and Traffic Separation Schemes for conventional vessels, and autonomous routes for the automated vessel, allow for increased predictability. We claim that in the process of designing such regulation, users from all component systems in the MTS should be invited to present their perspectives to make sure regulations are not seen as improper limitation of their flexibility.

A prominent finding in the study is that the VTS stated that they need to take a different role in the future MTS regardless of autonomy. The main contributor to this development is digitalisation. With more and better information made available to the vessel, the present VTS role diminishes. However, a different role of integrating information emerges. They claim their new role is a shift from solving situations ad-hoc to take a tactical responsibility to plan and avoid conflicts at an early stage. This reflected in their suggested measures of using time-slots and a stricter use of clearances. To allow for automated vessels, such development will be a pre-requisite, and additionally, in combination with other measures such as automated solutions for resolving traffic conflicts and more use of reporting and supporting systems to integrate information and decision support. The study also shows that the VTS expects the automated vessel to be reliable, have redundant back-up systems, and being able to bring to full stop if needed. The automated vessel should be easy to see using conspicuity paint and special AIS-tags.

The prototype of the MTS shows a challenging voyage for the automated vessel. Conflict situations based on the challenges mentioned by the participants were combined with solutions discussed in the ideation phase. Even though several conflict situations were presented, no situation remained unsolvable. This could partly be caused by the set-up of the study where the same participants discuss challenges and solutions. However, the participants from VTS have nautical experience and are expected to reveal immediate challenges in the scenario. The prototype showed that the systems perspective on safe coexistence opposed to as safe, or safer vessel, is valuable. The responsibility of separating automated vessels from conventional vessels was shared between all system components in the MTS. However, if this responsibility sharing is acceptable to all users is still unanswered, and in design of the future MTS this needs to be explored further.

The conclusion of the study is that the Vessel Traffic Services believe they could have major contribution to a safe coexistence between automated vessels by regulating and organising traffic. However, safe coexistence does not occur with the VTS alone, it also implies changes to all component systems in the MTS. A promising finding is that the measures suggested by the VTS is not seen as futuristic measures difficult to implement. On the contrary, the VTS states “this is not difficult; we could do it tomorrow”.

Declaration of interest statement

No potential conflict of interest was reported by the authors.

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Figures

Data

The data that support the findings of this study are available on request from the corresponding author, TR. The data are not publicly available due to containing information that could compromise the privacy of research participants.