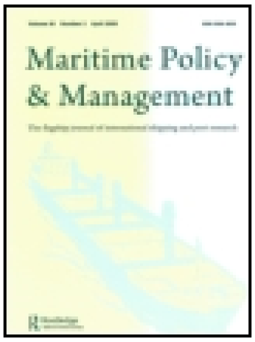

Routledge
Taylor & Francis Group

Maritime Policy & Management

The flagship journal of international shipping and port research

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tmpm20

The contribution of Vessel Traffic Services to safe coexistence between automated and conventional vessels

Tore Relling, Margareta Lützhöft, Runar Ostnes & Hans Petter Hildre

To cite this article: Tore Relling, Margareta Lützhöft, Runar Ostnes & Hans Petter Hildre (2021): The contribution of Vessel Traffic Services to safe coexistence between automated and conventional vessels, Maritime Policy & Management, DOI: 10.1080/03088839.2021.1937739

To link to this article: https://doi.org/10.1080/03088839.2021.1937739

Published online: 12 Jun 2021.

MARITIME POLICY & MANAGEMENT
https://doi.org/10.1080/03088839.2021.1937739

The contribution of Vessel Traffic Services to safe coexistence between automated and conventional vessels

Tore Relling [a], Margareta Lützhöft [b], Runar Ostnes [a] and Hans Petter Hildre [a]

[a]Department of Ocean Operations and Civil Engineering, Norwegian University of Science and Technology, Aalesund, Norway; [b]Department of Maritime Studies, Western Norway University of Applied Sciences, Haugesund, Norway

ABSTRACT

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 several years, no autonomous concepts have become operational. 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 Vessel Traffic Services (VTS) traffic regulation and organisation measures in a 2025 scenario. The study shows that the 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

1. 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 several years, 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.Table 1

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.

CONTACT Tore Relling tore.relling@ntnu.no Norwegian University of Science and Technology, Aalesund, Norway

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.

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

Using the 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 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.

1.2. The interplay between VTS and MTS

The VTS is described as a sociotechnical control system in the MTS (Praetorius 2014), where the MTS being a system-of-systems composed by the systems involved in navigation in an area (Relling et al. 2019a). Being a *sociotechnical* system (Relling, Praetorius, and Hareide 2019b), 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

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

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 the 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 2019b). 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. 2019a). 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. 2019a).

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.

1.3. 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 n.d.). 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)

1.4. Objective

In this paper, we focus on a first 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?

2. 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, Link, and Leifer (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. The paper follows the flow in Figure 1.

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.

Figure 2 visualises the focus areas for the various stages of the study. The introduction chapter presents our stance related to situation analysis, goals and situation variants. The situation analysis describes how digitalisation opens for new maritime solutions, but no concept of autonomy has yet been put into operations. The goals are to explore the VTS role to facilitate for safe coexistence in a future MTS and to include the humans in the digitalisation of the industry. The situation variants are framed by the premises for the study and considering the VTS as a control system. Further, the results chapter presents the ideation phase and finally, the development and testing of a prototype.

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.

2.1. Sampling

The selection of participants was planned in cooperation with the NCA. Since the NCA was involved in deciding 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.

2.2. 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 the NCA 16 September 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'.

The workshops covered the following questions:

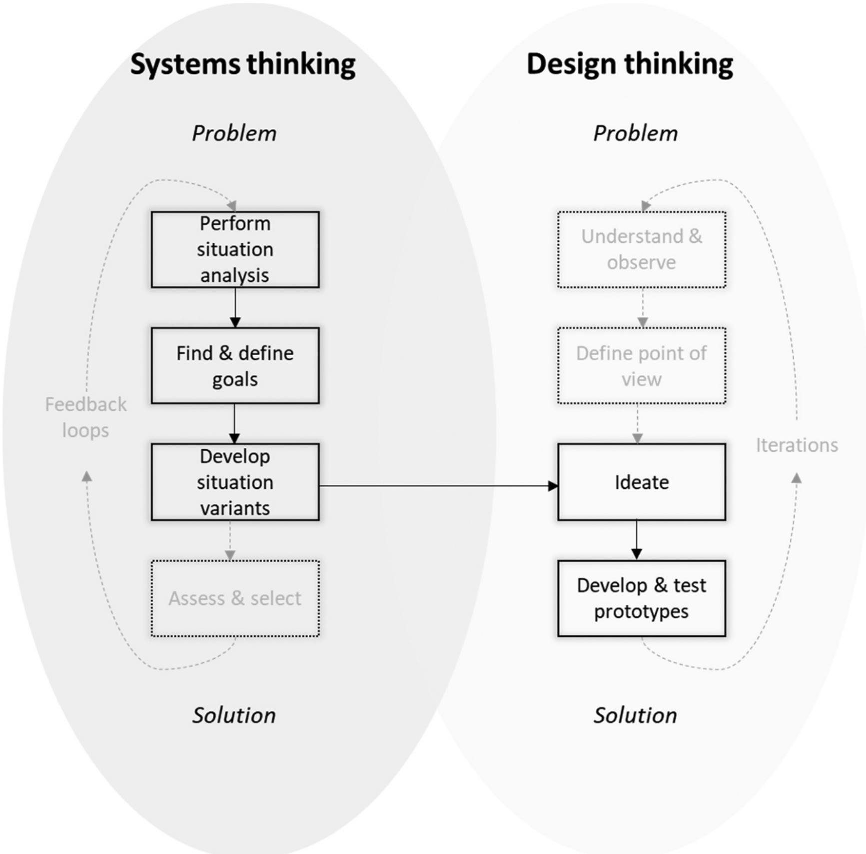

Figure 1. The processes in systems thinking and design thinking have many similarities and Lewrick, Link, and Leifer (2018) suggest combining these mindsets. The highlighted process steps from the figure adapted from (same citation as above) are used in this study. The three systems thinking process 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.

(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?
(3) Does the prototype reflect your statements from the first workshop?
(4) What situations would be most challenging in the scenario?

2.3. Analysis

All focus group discussions and plenary discussions have been recorded and transcribed. The data was coded using Nvivo analysis software and deductively coded to four nodes: VTS Traffic regulation, VTS traffic organisation, Automated vessel and shore centre, and conventional vessel. The nodes were subsequently 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.

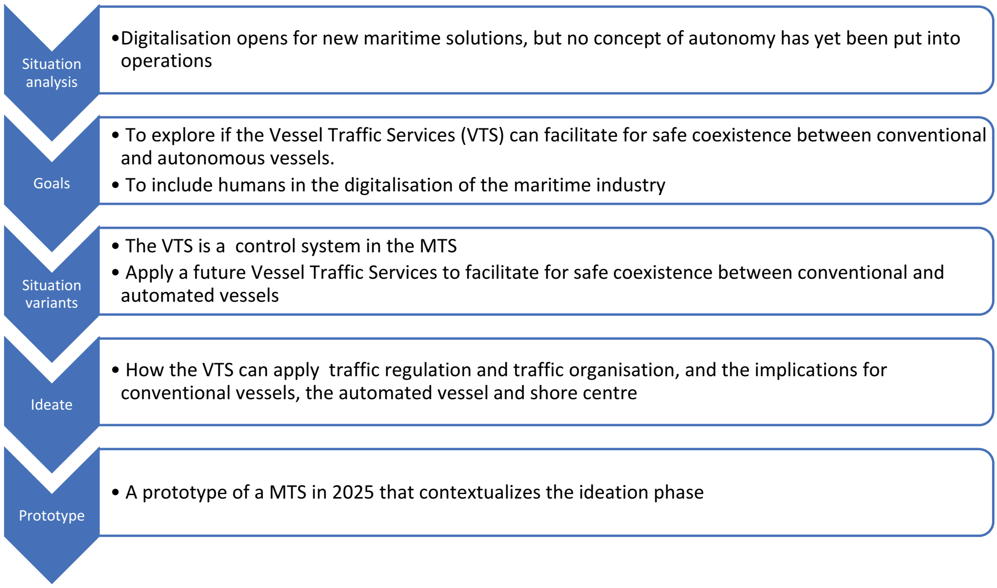

Figure 2. The focus areas for the various stages of the study.

2.4. 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 inevitably 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 limit the generalisability to a broader autonomy discussion.

3. 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.

3.1. 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 opinions, since 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.

3.1.1. 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 often 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)* as described in COLREG's rule 10. The VTS believes that both standardised routes and TSS should be used by conventional vessels only, also after implementation of automated vessels. However, both of the measures are important for separating conventional traffic from automated vessels, and to increase predictability and to detect deviations early.

The 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.

The VTS suggests autonomous operations should 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 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. The NCA should evaluate the concept and be responsible for an approval. The automated vessel is then only allowed to sail in the 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.

3.1.2. 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 allow for autonomous operation. They foresee that the VTS must take 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 measure allowing 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 say 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 must 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 help 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 with COLREG. The VTS does not see this as violating COLREG if 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 than 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, if an 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 act, 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 do 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.

3.1.3. 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 a new approval and clearance from the VTS. 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.

3.1.4. 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.

3.2. 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

4. Discussion

The results show that the participants have ideated a wide range of measures to facilitate for safe coexistence of automated and conventional vessels.Figure 4

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 Figure 5. 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 the 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 Figure 6. 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 say 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 Figure 7. 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 the 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 solutionsFigure 8.

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.Figure 9

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

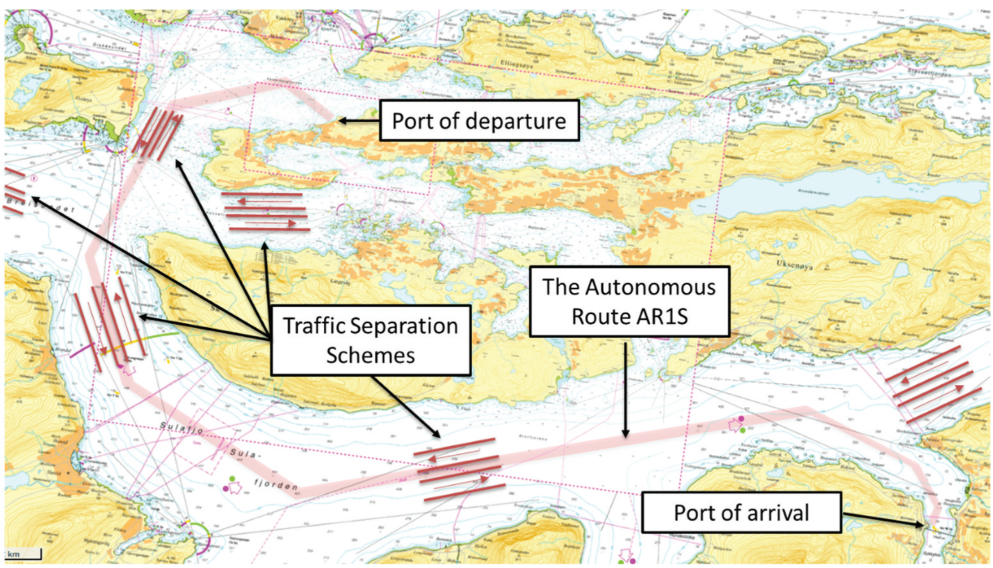

Figure 3. The prototype of the MTS with an automated operation in the autonomous route AR1S and Traffic Separation Schemes.

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 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 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.	

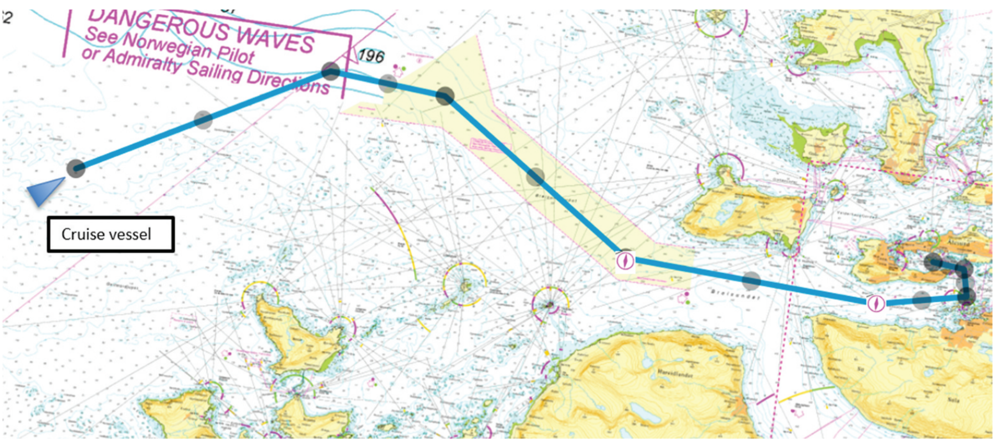

Figure 4. A cruise vessel reports to enter the area, and receives a condition-based clearance from the VTS.

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 summarises 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.

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.

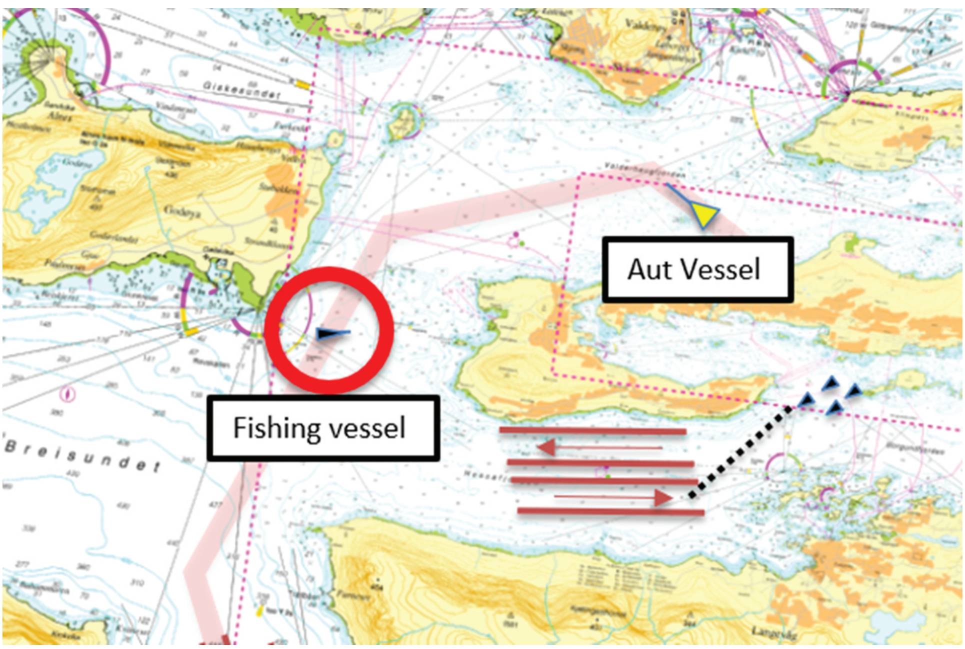

Figure 5. A fishing vessel starts fishing in the AR1S. The VTS is warned by an alarm.

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 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.

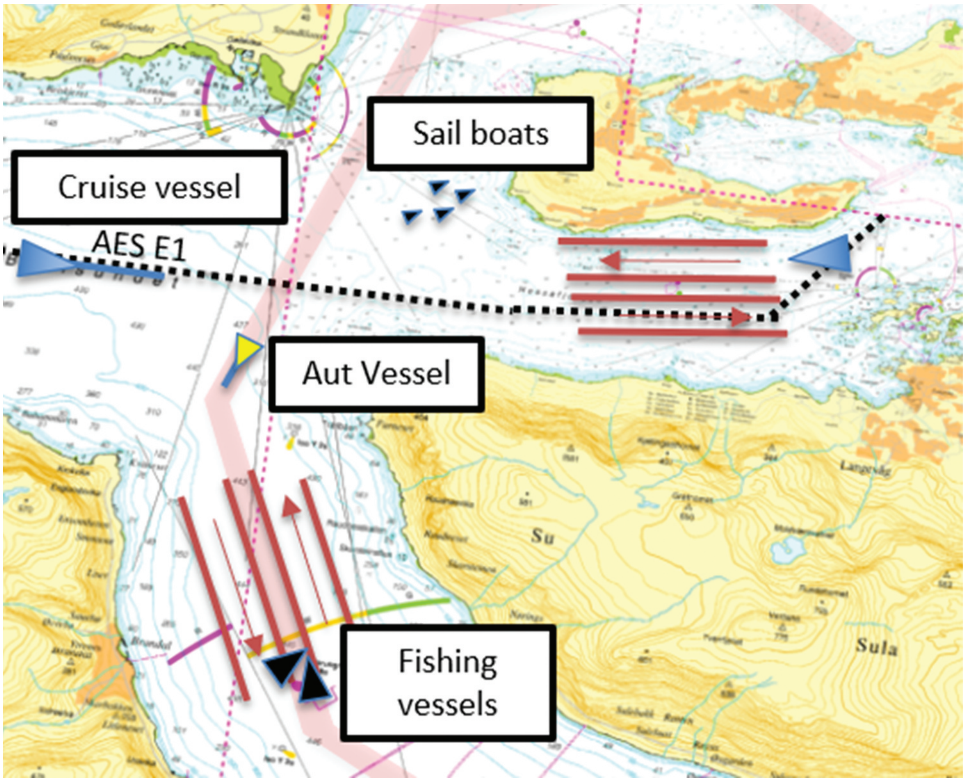

Figure 6. If a situation occurs in the autonomous route, the automated will reduce speed and never leave the autonomous route.

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 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.	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.

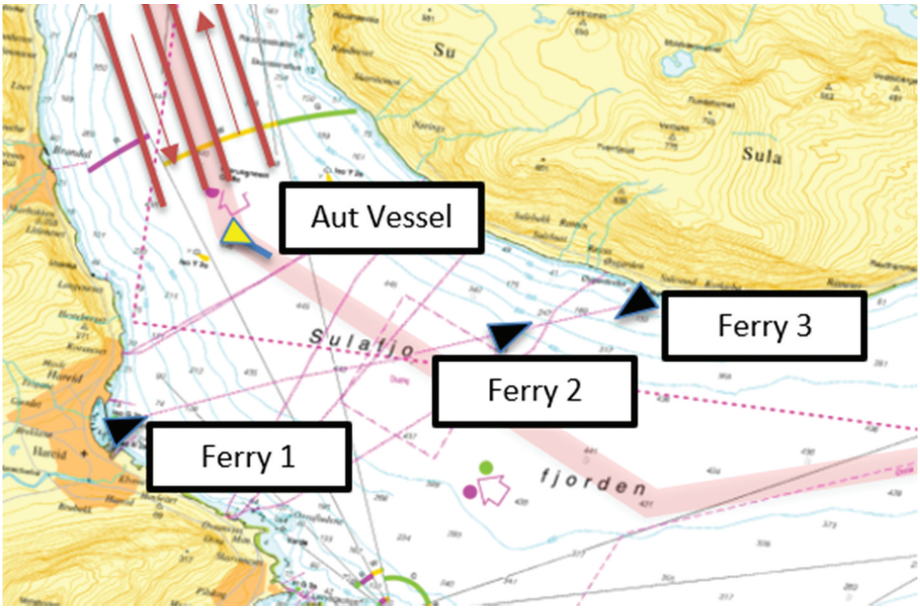

Figure 7. An automated solution to resolve situations between the automated vessel and vessels that frequently trafficking the area is suggested.

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.

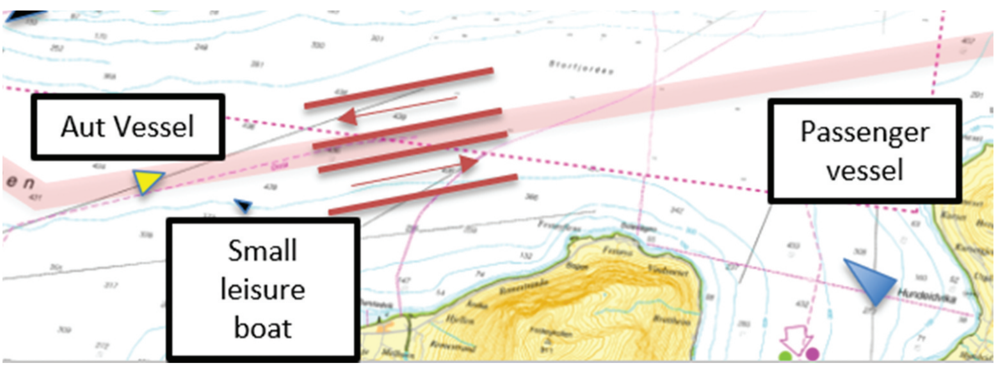

Figure 8. The automated vessel might experience conflict situation with vessels under VTS control and vessels not controlled by the VTS.

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.

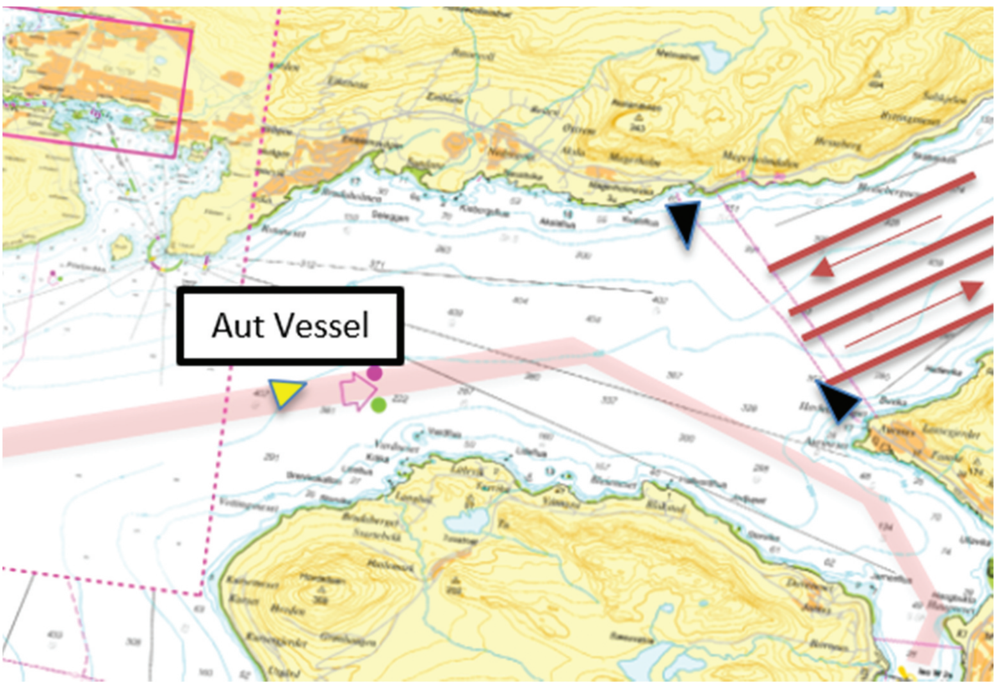

Figure 9. In case of a black-out, the automated vessel should have a back-up solution that keeps the vessel inside the autonomous route.

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 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 .	

5. Conclusion

In the study, we have explored if the future VTS can facilitate for safe coexistence between automated and conventional vessels. We have discussed a first 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 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 timeslots 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'.

5.1. 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.

Disclosure of potential conflicts of interest

No potential conflict of interest was reported by the author(s).

Notes on contributors

Tore Relling is a PhD student on the National Joint PhD Programme in Nautical Operations. He has a background from military air command and control and works as a principal consultant for DNV GL in maritime advisory. His PhD project is about the governmental role in maritime autonomy.

Margareta Lützhöft is a master mariner, trained at Kalmar Maritime Academy in Sweden. Presently she holds a position as Professor of Maritime Human Factors at the Maritime Safety (MarSafe) Research Program at the Institute of Nautical Studies, Western Norway University of Applied Sciences. Her research interests include human-centred design and the effects of new technology, and she has published in these and other areas relating to maritime safety.

Runar Ostnes is presently an associate professor at the Norwegian University of Science and Technology (NTNU) in Ålesund. He has obtained a Cand. Mar. (MSc Nautical Science, NTNU), a MSc in Defence Geographic Information (Cranfield University) and PhD in Hydrography (University of Plymouth). His area of expertise includes navigation, navigation systems, nautical operations, and hydrography. He has more than a decade of military operational experience in the Royal Norwegian Air Force serving as navigator on P3 Orion anti-submarine aircraft and Sea King rescue helicopters.

Hans Petter Hildre is professor and head of department of Ocean Operations and Civil Engineering at Norwegian University of Science and Technology (NTNU). Hildre is Centre Director for Centre for Research Driven Innovation (SFI-MOVE) within marine operations. This is cooperation between NTNU, SINTEF, University Sao Paulo and 15 companies at the west coast of Norway. Hildre is project leader at Global Center of Expertise – Blue Maritime. This is cluster organization for more than 200 companies at the west coast of Norway.

ORCID

Tore Relling http://orcid.org/0000-0002-7526-0187
Margareta Lützhöft http://orcid.org/0000-0002-3800-8126
Hans Petter Hildre http://orcid.org/0000-0003-1444-7818

References

Fishman, D. B. 1999. *The Case for Pragmatic Psychology*. New York: NYU Press. http://search.ebscohost.com/login.aspx?direct=true&db=nlebk&AN=100438&site=ehost-live

IALA. 2016. "VTS Manual Edition 6."

IMO. n.d. "Autonomous Shipping." "International Maritime Organization." Accessed January 20, 2020. http://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx

Lambrou, M. 2017. "Shipping 4.0: Technology Stack and Digital Innovation Challenges." *IAME 2017 Conference*, no. June: 1–20. Kyoto, Japan.

Lewrick, M., P. Link, and L. Leifer. 2018. *The Design Thinking Playbook*. Hoboken, N.J.: John Wiley & Sons.

Lützhöft, M., A. Hynnekleiv, J. V. Earthy, and E. S. Petersen. 2019. "Human-Centred Maritime Autonomy - an Ethnography of the Future." *Journal of Physics: Conf. Series MTEC/ICMASS*. doi: 10.1088/1742-6596/1357/1/012032. November 13–14.

Maier, M. W. 1998. "Architecting Principles for Systems-of-Systems." *Systems Engineering* 1 (4): 267–284. doi:10.1002/(SICI)1520-6858(1998)1:4<267::AID-SYS3>3.0.CO;2-D.

Ministry of Transportation. 2019. "Sjøsikkerhet," March. https://www.regjeringen.no/no/tema/transport-og-kommunikasjon/kyst/sjosikkerhet/id2344626/

Mumford, E. 2006. "The Story of Socio-Technical Design: Reflections on Its Successes, Failures and Potential." *Information Systems Journal* 16 (4): 317–342. doi:10.1111/j.1365-2575.2006.00221.x.

Porathe, T., J. Prison, and Y. Man. 2014. "Situation Awareness in Remote Control Centres for Unmanned Ships." Human Factors in Ship Design & Operation, no. February: 1–9.

Praetorius, G. 2014. "*Vessel Traffic Service (VTS): A Maritime Information Service or Traffic Control System? Understanding Everyday Performance and Resilience in A Socio-Technical* System *under Change*." [PhD-thesis].

Praetorius, G., C. Hult, and C. Sandberg. 2019. "Towards Autonomous Shipping - Exploring Threats and Opportunities in Future Maritime Operations." *In Advances in Intelligent Systems and Computing* 964: 633–644. doi:10.1007/978-3-030-20503-4_57.

Relling, T., M. Lützhöft, R. Ostnes, and H. P. Hildre. 2018. "A Human Perspective on Maritime Autonomy." In *Augmented Cognition: Users and Contexts*, edited by D. D. Schmorrow and C. M. Fidopiastis, 350–362. Cham: Springer International Publishing.

Relling, T., M. Lützhöft, H. P. Hildre, and R. Ostnes. 2019a. "Theoretical Issues in Ergonomics Science How Vessel Traffic Service Operators Cope with Complexity – Only Human Performance Absorbs Human Performance." *Theoretical Issues in Ergonomics Science*. 1–24. doi:10.1080/1463922X.2019.1682711

Relling, T., G. Praetorius, and O. S. Hareide. 2019b. "A Socio-Technical Perspective on the Future Vessel Traffic Services." *Necesse* 4 (1): 112–129. doi:10.21339/2464-353x.4.1.1.

Rolls-Royce. 2016. "Autonomous Ships: The Next Step." In *AAWA: Advanced Autonomous Waterborne Applications*, 7. Ship Intellingence Marine.

Stanton, N. A., P. M. Salmon, L. A. Rafferty, G. H. Walker, C. Baber, and D. P. Jenkins. 2013. *Human Factors Methods - A Practical Guide for Engineering and Design*. 2nd. Vol. 53. Surrey, England: Ashgate Publishing Limited. doi: 10.1017/CBO9781107415324.004.

Wilson, J. R., and S. Sharples. 2015. *Evaluation of Human Work*. Boca Raton: CRC Press.