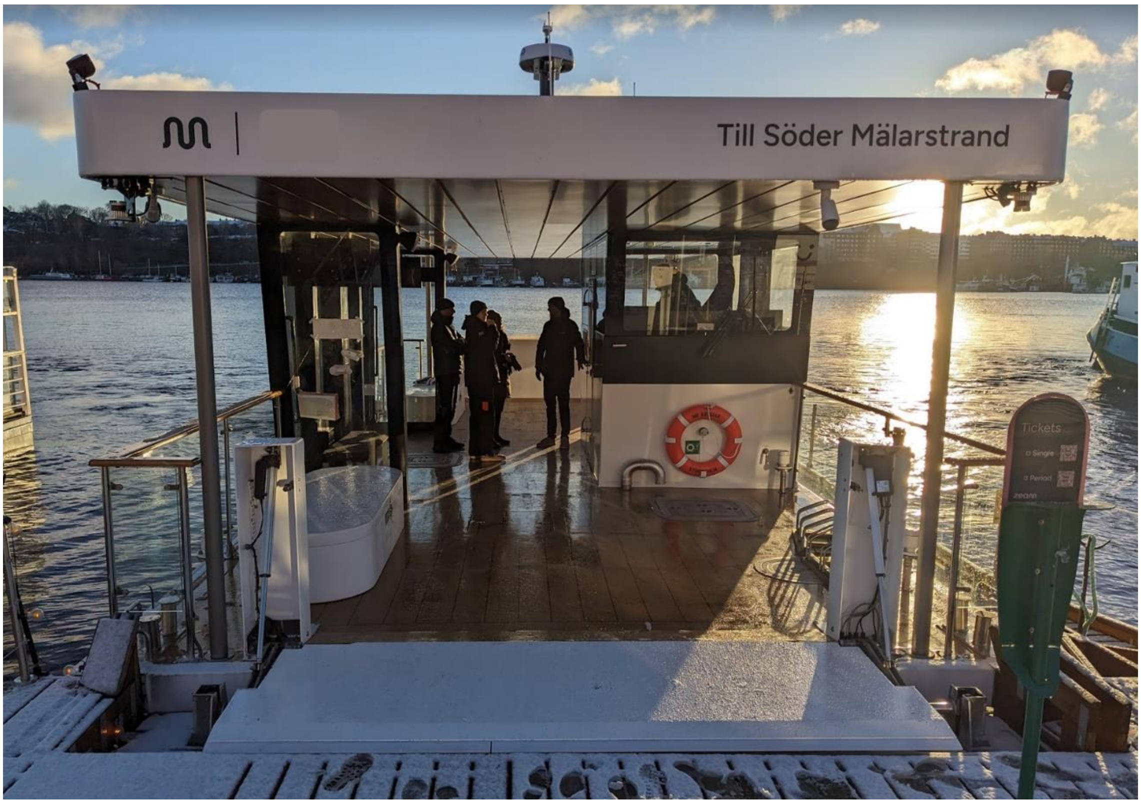
SAFETY AND TRANSPORT
MARITIME



Operating MASS Passenger Ferry MF Estelle - Shifting Work from Ship to Shore

Nicole Costa, Victor Fabricius

RISE Report : 2024:110

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Abstract

Maritime Autonomous Surface Ships (MASS) refer to vessels that can be remotely controlled or operate independently of human interaction to a higher degree. This report is part of the deliverables in the project "Policy Lab Urban Zeas (PLUZ)" exploring the safety case for automated public ferry transport based on pioneering trials with the ferry MF Estelle crossing Riddarfjärden in Stockholm. This report takes a Human Factors perspective on current and envisioned future operations including a shift of the human operator from ship to shore. It highlights incremental development stages towards establishing a Remote Operations Centre (ROC), from which an operator will supervise Estelle. The adaptation of operator tasks, functions, and responsibilities from ship to shore is shortly discussed, and so is the distribution of tasks and teamwork between the ROC operator and the remaining on-board passenger attendant.

Key words: MASS, passenger ferry, remote operations, human factors

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Content

1 Introduction

This section introduces the general concept of automated and autonomous ships as well as the specific project and pilot case from where this work was conducted.

1.1 Maritime Autonomous Surface Ship (MASS)

According to the International Maritime Organization (IMO), "Maritime Autonomous Surface Ships (MASS)" refer to vessels that can be remotely controlled or operate independently of human interaction to a higher degree (IMO, 2019). There are many classifications today that categorize technological autonomy and operator control levels. In shipping, the IMO defined four generic levels, but classification societies like DNV, Bureau Veritas, and Lloyd's Register, have their own similar classifications defining the role of technology and that of the operator, as well as whether the operator is present or remote. In this report, we consider IMO's general classification (see Table 1), yet we go into more specific adapted levels for the "Estelle" pilot case, introduced in the next section.

Table 1. Levels of autonomy in MSC 100 (IMO, 2018).

	Autonomy Level	Description
1	**Ship with automated processes and decision support**	Seafarers onboard operate and control ship. Some operations may be automated and at times unsupervised but with seafarer onboard ready to take control.
2	**Remotely controlled ship with seafarers onboard**	Ship is remotely controlled. Seafarers are available onboard to take control and operate the shipboard systems and functions if needed.
3	**Remotely controlled ship without seafarers onboard**	Ship is remotely controlled. No seafarers onboard.
4	**Fully autonomous ship**	The operating system of the ship is able to make decisions and determine actions by itself.

1.2 The PLUZ Project and MF Estelle Pilot Case

The research project "Policy Lab Urban Zeas (PLUZ)" funded by the Swedish Transport Agency explores the safety case for urban automated public ferry transport. This is based on pioneering trials with the automated ferry MF Estelle, created and operated by the joint venture Zeam, providing a publicly available passenger service crossing Riddarfjärden in Stockholm (see Figure 1). Additional project partners include Port of Stockholm and DNV.

The ferry is operating between Kungsholmen and Södermälarstrand in Stockholm. This route was selected since there was no previous ferry service in this area and the waters are relatively sheltered and traffic-free. This is an area that includes only the occasional larger ferry, recreational boat or similar fairway user. With an onboard crew member supervising the operation, the ferry navigates and docks autonomously based on a pre-defined route and various sensors and advanced marine technology.

Figure 1. Initial rendering of the ferry service (image: Zeam) and MF Estelle in operation in Stockholm, 2023.

2 A Human Factors Perspective

While the concept of MASS refers to "autonomous" ships, there are still humans involved in the everyday operations to meet both regulatory and practical requirements. Human Factors (or Ergonomics) is the scientific discipline that investigates the interactions between people and technology or other elements of a system, and provides input into the design of said system in order to optimize human well-being and overall system performance (IEA, 2000).

2.1 Estelle as Part of a Socio-technical System

Figure 2 depicts the Estelle ferry as part of a system linking humans, technology, and organizations. Such a sociotechnical system is comprised of both social, technical, and organizational elements that function together towards a defined goal (Grech et al., 2008; Hendrick & Kleiner, 2001). In this case, Estelle is its own system with an operator, hardware and software, as well as passengers. However, examples of additional stakeholders in a wider perspective will also include other waterway users (e.g., other ferries, recreational boats, kayakers etc.) and services such as sea rescue that may interact with Estelle. These entities and actors are situated within a context of environmental conditions, regulations, cultures, norms etc.

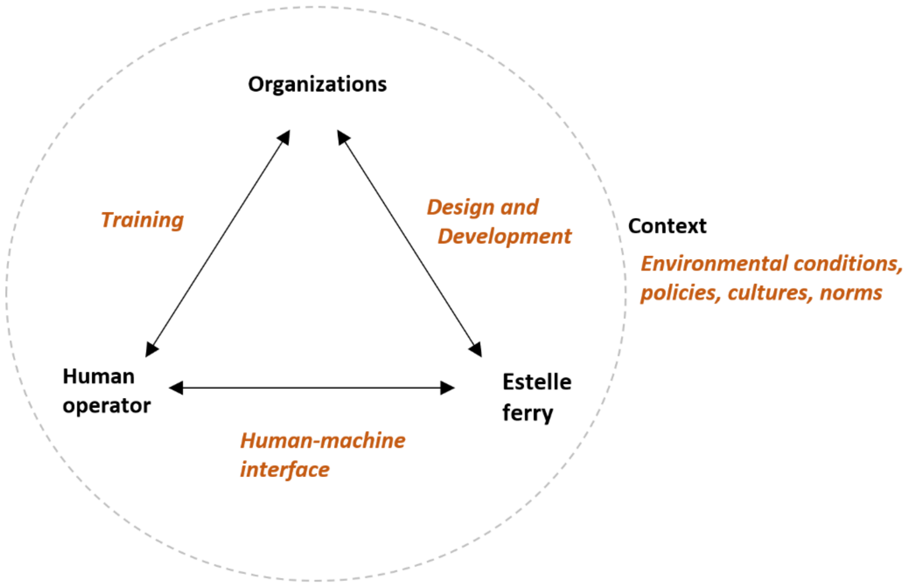

Figure 2. Outline of a sociotechnical system consisting of technical elements, humans, and organizations including examples of their relationships.

2.2 Taxonomy for MF Estelle

Table 2 presents a taxonomy which has been used for the specific MASS/ROC concept within the project.

Table 2. Taxonomy adopted in the project.

Degree of Automation and Degree of Control	Degrees of automation may include *no, low, partial, constrained*, and *full automation* of functions based on the response deadline for when a human operator will be required to intervene. Degrees of control may include *no, available, discontinuous, and continuous control* based on a maximum response time of a human operator. This classification (AUTOSHIP, 2021) relates to similar categorizations such as *active* or *passive supervision, delegated control, human in the loop,* etc.
Remote operations center (ROC) or Shore operations center (SOC)* **term originally used in the MUNIN project (MUNIN, 2015)*	Remote center from which operators supervise one or more ferries at a time and can intervene in the ferries' operations (on a tactical, operational, and/or strategic level) by interacting with available systems.
Remote operator	Remote operator performing supervision and interventions for one or more ferries at a time.
Workstation	Working environment where the operator can interact with the system, supporting information, alerts, requests of action etc. *via* different human-machine interfaces (HMI).
Intervention	Upon alert from HMI or based on operator's system error detection, operator intervenes and takes control of the system remotely.
Ferry attendant or Safety host	Crew member manning the ferry representing the ferry operations' company onboard and covering functions such as: • passenger information • safety procedures • tasks (still) requiring manual work • regulatory demands
Monitoring HMI (onboard)	Simplified system that provides information regarding voyage status to passengers and crew member. The system cannot be interacted with. Informational HMIs can also be directed at passengers for travel information etc.
Operational envelope (OE)	Contextually based design space and requirements for specific MASS solutions.
Minimum risk condition (MRC)	System state if an operator fails to meet a required response deadline. Is part of a fallback space as backup if the vessel falls out of the OE.

2.3 Performance Shaping Factors for Operators

While Human factors related insights are relevant for all interactions between people, organizations, and technology, the focus of this document is on the prospect of shifting human operation and supervision from onboard the vessel to the shoreside. Similarly to any other type of operator work, outcomes and performance (including safety) will depend on a range of conditions affecting the human operator. Examples of these conditions or "Performance shaping factors" (PSFs) include: 1) Working environment and tools, 2) Training and experience, 3) Task complexity, 4) Time constraints and stress, and 5) Teamwork. These are briefly presented in the following sub-sections and each topic also include two examples of possible Human factors related research questions. User-centered design (UCD) is as a suitable framework for proactively addressing these factors and related research questions, and to counter long-established "ironies of automation" (Bainbridge, 1982) where for example the human is left responsible for tasks that cannot be automated while experiencing issues such as monitoring fatigue and deskilling.

2.3.1 Working Environment and Tools

Various actors have presented concepts of physical- and digital working environments for MASS remote operations. These concepts may be tailored for different use cases and initially be tested and refined in lab settings (see example in Figure 3). One central initiative is the OpenRemote framework aiming for open-source assets and harmonized development between different developers and stakeholders, both in terms of front-end characteristics such as symbols, colours, and other graphical design elements as well as for implementation standards (OICL, 2024). Possible research questions include:

- *What should the physical/digital layout be for generic/specific ROCs?*
- *How should human-machine interfaces (HMIs) be designed to support key aspects such as situational awareness?*

2.3.2 Training and Experience

It is not yet established what specific training and experience that is suitable for future MASS remote operators or for remaining onboard crew, and to what extent today's requirements will align. Initial research did for example find that both experienced gamers and navigators have relevant and transferrable skillsets, however, neither group excelled (Veitch et al., 2024). There are certainly relevant parallels between MASS remote operators and related roles such as air traffic controllers and various passenger-oriented attendants. Possible research questions include:

- *What training/skills are needed for effective, efficient, and safe MASS remote operations?*
- *How are relevant skillsets maintained over time?*

2.3.3 Task Complexity

Envisioned MASS operations can be divided into phases such as shore activities, leaving/arriving dock, and transit to location, and there are many other factors that may affect both how the work is designed and executed. It is crucial to consider the everyday tasks for remote operators and how it will contribute to working conditions and aspects such as cognitive over- and underload etc. Possible research questions include:

- *What are planned/idealized working tasks and activities (work-as-imagined) vs. what are the actual working strategies (work-as-done)? Are there any gaps?*
- *How is task overload and/or reduced vigilance mitigated and balanced?*

2.3.4 Time Constrains and Stress

MASS remote operations will potentially include time-critical work and emergency scenarios, drastically affecting the conditions for the operator. Possible research questions include:

- *What are possible critical events and how can these be tested?*
- *How is situational awareness supported during critical events?*

2.3.5 Teamwork

Effective collaboration and teamwork are often considered central to successful joint activity, where established research include teamworking theory, Computer Supported Cooperative Work (CSCW), and Human-automation interaction. Topics such as take- and handovers and achieving appropriate levels of trust will be highly relevant for MASS remote operations, and the development of more capable AI agents has also increased focus on human-AI teamwork. Possible research questions include:

- *How do actors collaborate within/between ROCs?*
- *Will there be teamwork between operator-automation and, if so, how is this supported?*

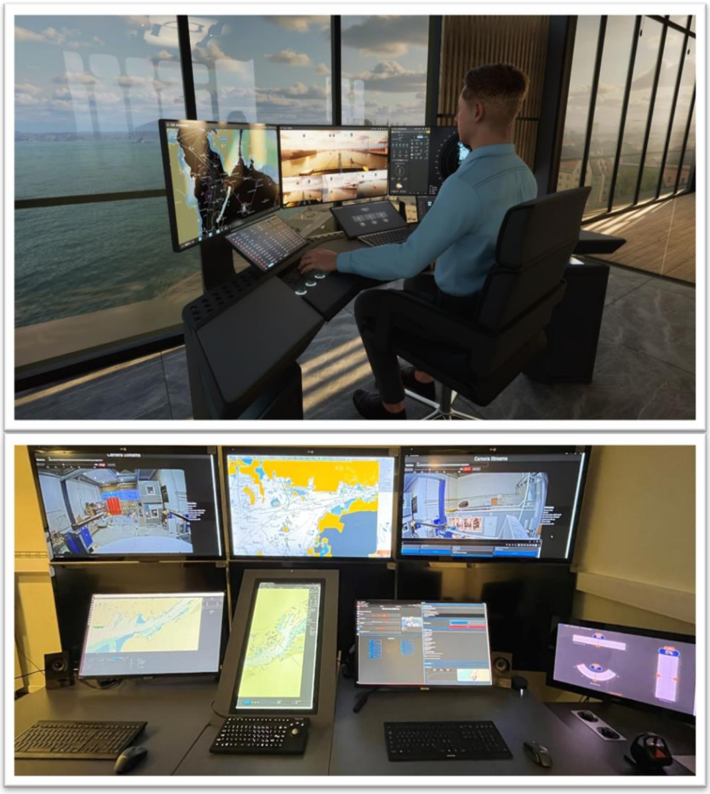

Figure 3. ROC concept above (Image: OICL/OpenRemote) and Usability Lab setup (RISE/SSPA) below.

3 Development Steps and Related Operator Roles and Responsibilities

Figure 4 shows a simplified overview of the development stages that the Estelle concept is currently planned to go through before it can reach the long-term goal ("minimum viable operations") of having a single ROC operator supervise two or more ferries simultaneously with a passenger attendant on each vessel. This stepwise development (where the PLUZ project is focusing solely on the initial stages) is largely motivated by the need to gradually test technical implementations, collect operational data, and to make iterations that can be communicated to regulators and other stakeholders. However, the continued Human factors analysis of the pilot case will focus on the current operations (as they were during fall 2023), and on the future step where Estelle is operated remotely via a ROC.

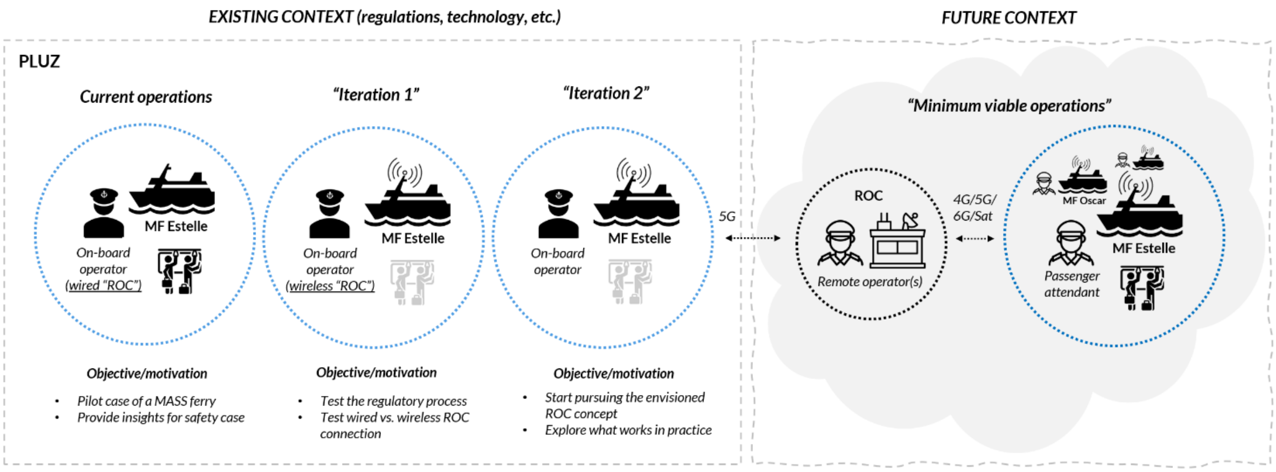

Figure 4. Current operations setup (left), planned development stages throughout the PLUZ project (iteration 1 and 2), and envisioned future operations (right).

3.1 Readiness Levels

Degrees or levels of automation can be related to Technology Readiness Levels (NASA, EU, etc.) that describe a number of steps for a specific technology and solution to reach maturity, going from early concept to prototype to viable product. Extending the technology focus with a broader innovation perspective will highlight additional dimensions to bring the innovation to deployment/implementation level, as seen in the more recent *Innovation readiness model* (see Figure 5).

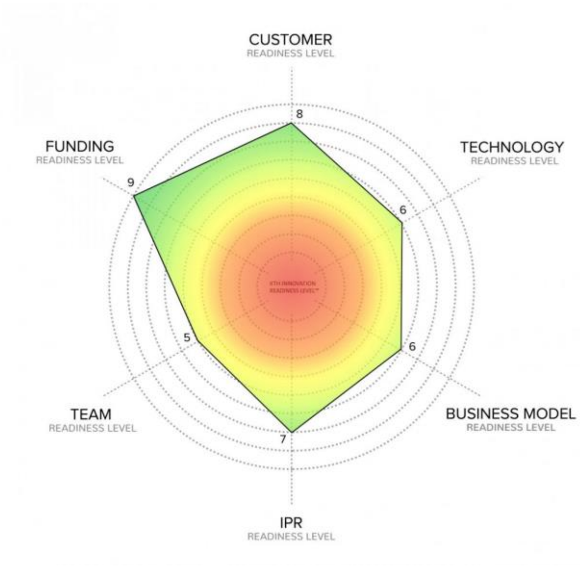

Figure 5. Example of the Innovation readiness model (KTH, 2018).

In terms of Estelle and the scope of the PLUZ project, elements that have been considers here include technological enablers required for the vessel automation system and the ROC; "customer" pertaining to the passengers; and the "team" including onboard crew and ROC operator. Another essential dimension that is at the core of this project and of the MASS-related agenda is policy and regulations that can accommodate the operations of MASS vessels. Based on these delimitations, an initial overview of how readiness levels can be estimated for the stages of implementation in this project is seen in Figure 6 below:

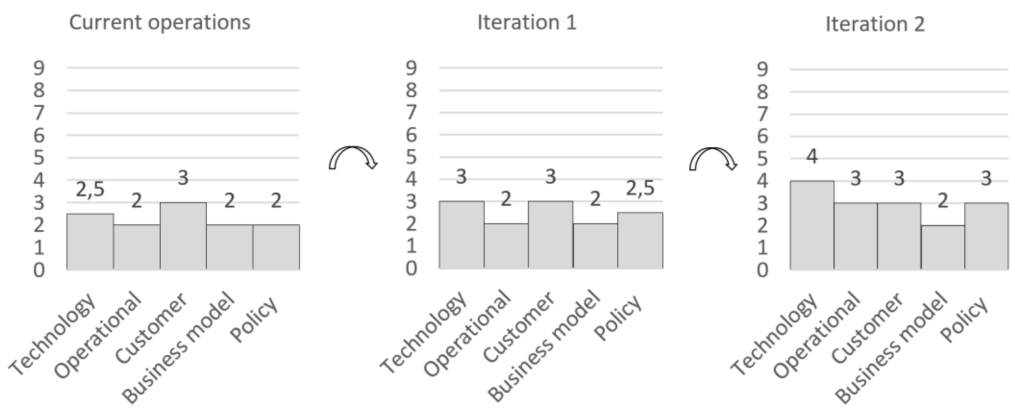

Figure 6. Estimated readiness levels per development stage.

3.2 Current Operations

In the current development stage (fall 2023), as there is an officer onboard and no existing remote operations up and running, the general arrangement of the ferry includes a bridge (see Figure 7) for monitoring navigation and manoeuvring, as well as for taking manual control if needed.

Figure 7. Bridge on the Estelle ferry where the officer monitors and controls the system if needed.

The bridge needs to be manned and have the necessary equipment for the officer to monitor the automation system and the fairway, to report emergencies, and to take manual control of navigation and manoeuvring if necessary (see Figure 8 for console layout, ECDIS and sensor interfaces). Route planning is not a necessary task to perform onboard as this ferry follows the same route continuously, which is a pre-established route uploaded into the system in advance. In the near-term, more tactical planning will be done on-route, choosing from pre-set routes (however, this choice may be performed by the automation system rather than the operator). [1]

Currently, the officer onboard has traditional master mariner training and certifications. There is no shore operation centre available during this first stage, hence the officer onboard performs all necessary tasks independently. However, as the ferry is generally capable of running in automated mode, the officer's main task is to actively supervise navigation and to take action if/when needed. As the tasks performed by the officer today are based on the implemented automation technology, the operator's role/functions may need to be adapted as the system is further developed. An initial list of current tasks and functions is provided in Table 3:

[1] There will soon be three available pre-set route plans that the officer can manually choose from to run automatically, depending on the need to avoid an object present in the water, or based on weather and current optimization. In the future, the system may instead include a machine learning algorithm learning from the officer's choices of routes, to automatically choose routes. Currently, there is only a single route, and the ferry will slow down for any object in the water until it moves away, or until the officer overrides the slowing-down function (the system cannot currently classify the objects in the water, so it will stop/slow down equally for every object).

Table 3. Examples of tasks and functions of the officer onboard Estelle.

Category	Task/Function
Supervise navigation	SN1: Supervise automated docking
	SN2: Initiate a new departure and route manually by pressing "start" (based on a fixed time schedule)
	SN3: Supervise automated navigation/transit/crossing based on a pre-set route plan
	SN4: Station keeping/dynamic positioning manually if ferry needs to stay in the same spot without dropping anchor
	SN5: Take manual control when needed
	SN6: Drop anchor if needed
	SN7: Have communication with the shore centre when needed
	SN8: Report objects in the water that go undetected by the system (visually in the automation HMI) will soon be implemented as well
Supervise deck equipment	SD1: Taking down and up passenger ramp (manual command)
Supervise engine machinery	SEM1: Monitoring battery pack status; battery isolation test/state of health (yearly)
Passenger handling	PH1: Supervise passenger boarding and offboarding
	PH2: Press emergency stop if safety emergency occurs with passenger boarding/offboarding
	PH3: Provide information and assistance to passengers
	PH4: Call for emergency assistance when needed
	PH5: Onboard safety procedures and medical assistance certificate
	PH6: Remote safety procedures
Emergency procedures	EP1: Putting out fire onboard
	EP2: Man overboard (MOB)
	EP3: Evacuating passengers

Figure 8. Console on the bridge of the ferry. The screen at the bottom of this figure is an ECDIS with an overlay of the automation system. The screen to the middle right of this figure is a type of conning display that is part of the automation system and provides information from the sensors located on all four ends of the ferry, and the screen to the middle left of this figure shows the rudder angles. Below the screens on the bridge, there is a joystick and levers for manual control.

3.3 Envisioned Future Operations

These descriptions and analyses are based on the “minimum viable operations”-stage previously shown in Figure 4.

3.3.1 Remote Operator

A future milestone in the development is to be able to shift operations to shore, starting with one ROC operator per ferry at a time (see Figure 9). Later, one ROC operator may monitor two or more ferries simultaneously, and the ferries are not necessarily operating in the same geographical location.

Today, regulations still mandate the person onboard to be educated as a mariner, however this may change as the role and working conditions of ROC operators advance. In the near-term, the ROC operator is still expected to have had traditional master mariner training, certificates, and experience, and perform most of the same tasks as before, though remotely and in collaboration with an onboard crew member.

In the future, the current role and responsibilities of the onboard officer may be divided between the remote operator and an onboard role. While it is expected there will be teamwork between these roles for various functions of the operations, the main focus of the onboard crew lies on passenger assistance and safety procedures.

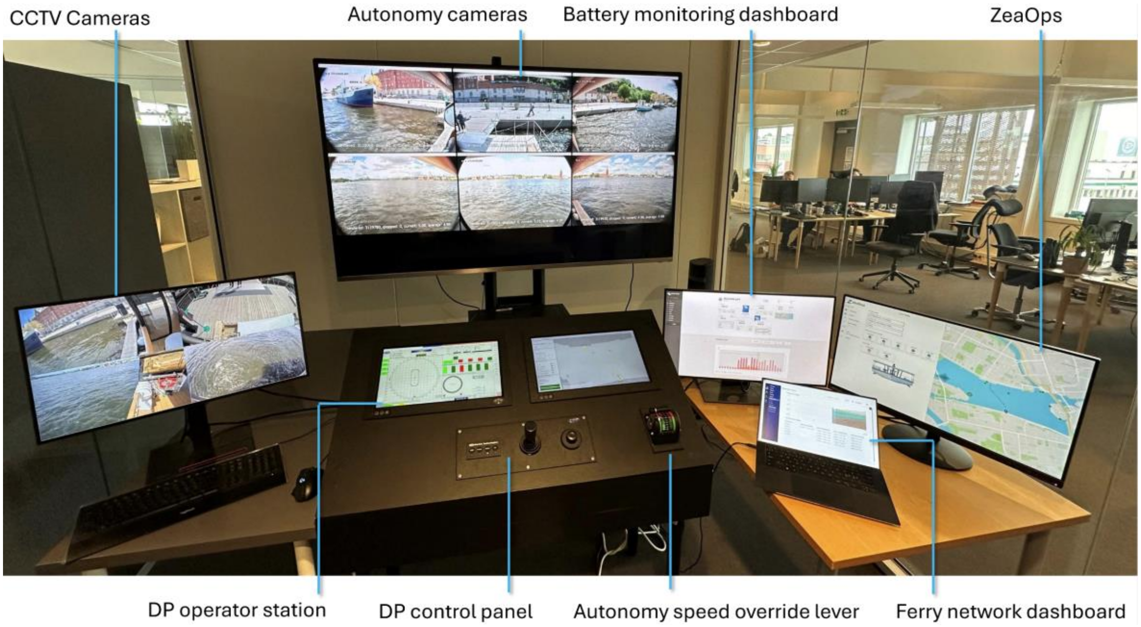

Figure 9. Initial setup of the ROC (image: Zeam).

3.3.2 Onboard Attendant

The onboard (ferry/passenger) crew member that is planned to remain onboard has clear parallels with the position of flight attendant or train crew. Their roles will typically include a wide range of tasks and functions that cater to and assist passengers such as information, stowing luggage, serving, maintaining the organization and cleanliness, as well as aiding the pilot/driver and managing general onboard safety, including preparing passengers for and coordinating emergency procedures, etc. This work can be connected to stages such as preparations, safety procedures, conflict resolution, coordination activities, and post-service duties. Based on the list of task categories presented above and on further discussions held with Estelle's technology provider and operator, a task/responsibility distribution table between operator and attendant was made as follows (see Table 4):

Table 4. Distribution of tasks between ferry attendant and shore operator. √ = responsible for the task; (√) = involved in the task upon request from RO or shipping company.

Source		Responsibilities & Tasks/functions	"Current"	"PLUZ"		"Future"	
			Onboard Officer	***"Shore** Operator"*	***"Ferry** Attendant"*	***"Remote** Operator"*	***"Passenger** Attendant"*
STCW	II/3	- Supervise navigation	√	√		√	
		- Supervise machinery	√	√		√	(√)
	II/5	- Supervise all bridge equipment	√	√	√	√	
		- Supervise all deck equipment	√	√	√	√	(√)
		- Supervise vessel stability, integrity, and ballast mgt.	√	√		√	(√)
	III/5, III/6	- Supervise all engine machinery and equipment	√	√		√	(√)
		- Supervise all electrical equipment	√	√	√	√	(√)
	V/2	- Passenger handling	√	√	√		√
The Swedish transport agency		- Being able to keep a safe watch (bridge, engine, and radio)	√	√		√	
		- To complete the mooring work	√	√		√	(√)
		- To prevent damage to the environment	√	√		√	
		- To be able to safely handle the cargo on board, the number of people and their tasks	√	√	√		√
		- To be able to manage the healthcare on board	√		√	(√)	√
		- To handle safety maintenance and cleaning	√		√	√	
		- To be able to handle fire on board	√	√	√	(√)	√
		- To manage maritime security on board	√	√		√	
		- Handling lifesaving equipment	√		√	(√)	√

In steps 2-6, there is some redundancy in the different tasks in terms of having the ROC operator involved as well as the ferry/passenger attendant, whereas in the current scenario each task has only one operator involved (onboard). This definition of roles is hereby proposed but not yet tested in safety-critical scenarios, outside of normal operations. Accident/incident scenarios could include fire and emergency evacuation, collision, grounding, blackout/stop, loss of communication with shore, object in the water that goes undetected, passenger overboard, passenger with medical emergency, altercation between passengers, criminal activity onboard or cybersecurity issue etc.

4 Conclusions and Future Work

MF Estelle constitutes one of the first MASS passenger ferry trials and the PLUZ project has started to explore this innovation in terms of intersections between technology, policy, people, and organizations. For this deliverable which focuses on Human Factors and current and future operations, the main conclusions are as follows:

- MASS innovations cannot solely focus on the “ship” as it will be situated in a wider socio-technical system and context.
- The Human Factors discipline has a long tradition of studying and providing insights for task- and teamwork in various domains. For the MASS/ROC concept, key topics include performance shaping factors of operators such as: 1) working environment and tools, 2) training and experience, 3) task complexity, 4) time constraints and stress, and 5) teamwork.
- We recommend a User-centered design approach and to proactively address traditional challenges such as designing for situational awareness, trust calibration, appropriate workload, and skill preservation.
- Specifically, increased degrees of automation may lead to well established human-automation issues (i.e., “ironies of automation”) including monitoring fatigue, the need of even more skilled operators, and take- and handover issues.
- Additional proof-of-concepts of technological capabilities is needed to in more detail understand when and how humans may need to complement and compensate any automation to cover the whole set of requirements in the urban waterway use case.
- Future studies could address a wide range of topics and research questions related to MASS/ROC development including the design of human-machine interfaces (HMI), educational requirements, safety/risk analysis, and effective teamworking formation. It is also crucial to address these aspects based on various emergency scenarios.

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